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## Measuring Expressive Music Performances: a Performance Science Model using Symbolic Approximation

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# Measuring Expressive Music Performances: a Performance Science Model using Symbolic Approximation

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Submitted in partial fulfilment of the requirements for

PhD

Technological University Dublin

Supervisors:

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Dr. Paul McNulty

Conservatory of Music and Drama

March 2019

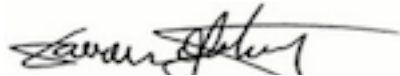
# Declaration

I certify that the this thesis which I now submit for examination for the award of PhD is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work.

This thesis was prepared according to the regulations for graduate study by research for the Technological University Dublin and has not been submitted in whole or in part for another award in any third level institution.

The work reported on in this thesis conforms to the principles and requirements of the Technological University Dublin's guidelines for ethics in research.

Signature:

A handwritten signature in black ink, appearing to read 'Ewan Stewart', written over a light grey rectangular background.

Date:

March 2019

# Dedication

I dedicate this dissertation firstly to Mary, Stephen and James. The sustained level of musical accomplishment in our home reinforced my interest in performances—particularly of twentieth-century music. I also want to dedicate this work to my parents, Anne and Colm. They too loved music of all types and facilitated my formative musical education at the Royal Irish Academy of Music.



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# List of publications

- O Doherty, Eamon, 'Music for Church and Court: Influences on Marco Da Gagliano at Florence and Mantua' (MA Dissertation, Open University, 2008), 6.
- — —, 'Measuring Performances: Empirical Musicology in a Pantonal World', Society for Musicology in Ireland, 5<sup>th</sup> Annual Postgraduate Conference, (DIT Dublin, 2012)
- — —, 'Symbolic Approximation: An Approach to Comparing Aspects of Musical Performance' (presented at the Society for Musicology in Ireland: 7th Annual Postgraduate Students' Conference, Cork Institute/ Cork School of Music, 2014)
- — —, 'Saxify: Detecting Fraudulent Music Recordings' (presented at the SMI/ICTM-IE Annual Postgraduate Conference, Maynooth University: ICTM Ireland/SMI, 2018)
- — —, 'Music Performance Science: Analytics and Music Recordings', in *Proceedings of the 2016 Music Technology Workshop: Establishing a Partnership Between Music Technology, Business Analytics, and Industry in Ireland* (presented at the MustWorks16, UCD, Dublin, 2016), in Proceedings at [http://www.ucd.ie/t4cms/MusTWork\\_2016\\_Proceedings.pdf](http://www.ucd.ie/t4cms/MusTWork_2016_Proceedings.pdf), 56–62, Accessed: 20 September 2018

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\*\* Formal permission was granted to me by Peters, London to include extracts from the *Phantasy*. The shorter extracts were typeset by myself using MuseScore2 version 2.0.3.1 Copyright Werner Schweer and Others. MuseScore is published under the GNU General Public License at <http://www.musescore.org>, Accessed: 2 February 2017.

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I further acknowledge receiving an Anne Leahy Travel Award which allowed me to attend the International Symposium on Performance Science (2013) in Vienna and to spend time at the Arnold Schoenberg Archive.



# Abbreviations

AI	Artificial intelligence, and specifically machine learning
BWV	Bach-Werke-Verzeichnis
CHARM	Centre for the Research and Analysis of Recorded Music
CMPCP	Centre for Musical Performance as Creative Practice
CPS	Centre for Performance Science
CSEM	Computer system for evaluating music performance
dB <sub>spl</sub>	Sound pressure level (intensity) in decibels
DM	Dissimilarity matrix
ED	Euclidean distance
ETL	Extract, transform and load
HIP	Historically informed performance(s)
IC	Intensity contour
IOI	Inter-onset interval
kNN	k Nearest Neighbours
LD	Levenshtein distance
MDS	Multi-dimensional scaling
MIDI	Musical instrument digital interface
MIR	Music information retrieval
MPS	Music performance science
mS	Millisecond (= 1 thousandth part of a second)
PAA	Piecewise aggregate approximation
PAM	Partitioning around medoids
PCA	Principal components analysis
PF	Performance fingerprint
PM	Performance matrix
PN	Performance norm
SN	Score norm
SAX	Symbolic aggregate approximation
SV	Sonic Visualiser
SOM	Self-organising maps
ZCR	Zero-crossing rate

# Abstract

Music Performance Science (MPS), sometimes termed *systematic musicology* in Northern Europe, is concerned with designing, testing and applying quantitative measurements to music performances. It has applications in art musics, jazz and other genres. It is least concerned with aesthetic judgements or with ontological considerations of artworks that stand alone from their instantiations in performances. Musicians deliver expressive performances by manipulating multiple, simultaneous variables including, but not limited to: tempo, acceleration and deceleration, dynamics, rates of change of dynamic levels, intonation and articulation. There are significant complexities when handling multivariate music datasets of significant scale. A critical issue in analyzing any types of large datasets is the likelihood of detecting meaningless relationships the more dimensions are included. One possible choice is to create algorithms that address both volume and complexity. Another, and the approach chosen here, is to apply techniques that reduce both the dimensionality and numerosity of the music datasets while assuring the statistical significance of results. This dissertation describes a flexible computational model, based on symbolic approximation of time-series, that can extract time-related characteristics of music performances to generate *performance fingerprints* (dissimilarities from an ‘average performance’) to be used for comparative purposes. The model is applied to recordings of Arnold Schoenberg’s *Phantasy* for Violin with Piano Accompaniment, Opus 47 (1949), having initially been validated on Chopin Mazurkas.<sup>1</sup> The results are subsequently used to test hypotheses about evolution in performance styles of the *Phantasy* since its composition. It is hoped that further research will examine other works and types of music in order to improve this model and make it useful to other music researchers.

In addition to its benefits for performance analysis, it is suggested that the model has clear applications at least in music fraud detection, Music Information Retrieval (MIR) and in pedagogical applications for music education.

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<sup>1</sup> Thanks to Peters Limited, London for permission to include their editions of *Phantasy for Violin and Piano*, op. 47 by Arnold Schoenberg, © Copyright Henmar Press, Inc., New York for all countries of the world. Reproduced by kind permission of Peters Edition Limited, London.

“Music... will help dissolve your perplexities and purify your character and sensibilities and in time of care and sorrow, will keep a fountain of joy alive in you.”

Dietrich Bonhoeffer (1906-1945)

“All models are wrong, but some are useful.”

G.E.P. Box (1919-2013)

“It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts.”

Sherlock Holmes

# INTRODUCTION

This dissertation proposes an empirical approach to evaluating and comparing expressiveness in musical performances. The collection of techniques has been assembled into a software program, *Saxify*, and validated as a music research model against existing data and peer-reviewed results. Some limitations of this model will be identified together with some suggestions for future research. The core software is issued as Free Open Source Software (FOSS). This recognises the power of engaging additional researchers to contribute to its future development. The code is also published in the hope that it will gain collaborations from musicology researchers and data scientists in order to foster development.<sup>1</sup>

It is proposed that this fresh examination of intensity and its relationship to performance expressivity benefits from widening the scope of investigation to include acceleration rates and rates of change of dynamics. The importance of this re-examination, benefitting from multidisciplinary contributions, should not be underestimated. Software tools that are today available for audio research have enormous power and flexibility as compared with what was available even ten years ago although polyphony and performances of densely scored music continue to present significant challenges to their effectiveness. Automated beat detection algorithms do not yet provide sufficient accuracy under conditions of varying time-signatures. Applying such tools appropriately requires that domain competency in music be combined creatively with clear analytic approaches drawn from the broad school of data sciences.

The general approach herein is experimental, being developed around one major case study — Schoenberg’s *Phantasy* for Violin with Piano Accompaniment (Op. 47). An important part of the research was to validate the proposed *Saxify* model separately against Chopin performance data and relevant peer-reviewed results. There are several reasons for selecting the *Phantasy*: (1) there is a significant and available discography that is spread across the decades since composition; (2) it is short enough, typically around nine minutes playing time, to be manageable in terms of repeated analyses of dozens of available recordings; (3) the complexity of twelve-tone serial compositional technique means that conventional concepts of expressivity and listeners’ expectations,

---

<sup>1</sup> <https://eamonodoherty.github.io/Saxify/>

as commonly applied to art music performances, may not be taken for granted. In this respect, there is a degree of objectivity to be gained in using an appropriately automated system to gauge expressivity; (4) Schoenberg developed many different approaches to the *Grundgestalt* of his *Phantasy*, within a very short span of 166 bars while using widely varying rhythms and tempi;<sup>2</sup> (5) it is easier to model performance variables in a solo work, or for an ensemble where one part is significantly more important than the other (the violin contributes by far the most important musical material to the *Phantasy*).

In addition, it is worth noting that many other composers, works and instrumentations could have been considered, for example, the clarinet and cello/piano movements from Messiaen's *Quatuor pour la fin du temps*, or a movement from Berg's *Vier Stücke*, op. 5 for clarinet and piano. However, the final choice, among twentieth-century repertoire, was pragmatic, driven by ease of access to a body of quality recordings.

### **Contributions to Knowledge**

I argue forcefully that research into musical performances can benefit from studying recordings. Software tools, together with appropriate statistical techniques, are appropriate to ease the burden of calculating and measuring in order to facilitate unambiguous statements about performances. This dissertation, together with all the software that resulted from it, makes several contributions to musicology. It shows clearly that methods applied to time-series analysis in other domains may usefully be applied to MPS research to provide new ways of studying expressive performance. It proposes a technique to derive a *performance fingerprint* (PF) for a recording and establishes a model for comparing PFs to establish how far apart are performances from each other in respect both of specifically selected performance variables and their combinations. It demonstrates the value of theorizing and constructing a performance norm (PN) being a conceptual *musical performance average* of a set of performances. Consequently this is a consistent, quantitative approach to evaluating style change over

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<sup>2</sup> Schoenberg's conception of *Grundgestalt* is of a fundamental musical idea, not just in his serial compositions, that must be varied using the principle of 'developing variation'. This continuous re-development is in the intellectual tradition of Wagner, Mahler and Brahms. The drive behind this approach to composition is to create 'intellectual and emotional satisfaction'. See Michael Schiano, 'Grundgestalt', *Grove Music Online*, Accessed: 12 April 2018, <http://www.oxfordmusiconline.com/grovemusic/view/10.1093/gmo/9781561592630.001.0001/omo-9781561592630-e-0000011868>.

time, based on assumptions as to the variables that constitute a performance style. Furthermore, it offers flexibility in application and interpretation since it may be applied to complete performances, or to sections. Finally, this dissertation recommends encapsulating the analytical methods in mobile software for use as a research toolkit.<sup>3</sup>

### **Timeliness of this research**

This research is timely given that most empirical performance studies over the past twenty-five years or so, such as Repp's performance-based research on Schumann's *Traümerei*, have restricted explorations to absolute tempo and dynamics, and to relatively short, monophonic, nineteenth-century music.<sup>4</sup> New methods are needed to consider additional variables and rates of change, and to facilitate dealing with large amounts of data.

### **Expressivity**

Quantifying expressivity for measurement purposes is a particularly difficult problem. There is no objective agreement as to all the variables of music performance that make it up even though it is commonly suggested that tempo adjustments and subtle dynamic changes comprise the main musician's toolkit of expressive delivery. There are certainly more possibilities: colouring of pitch, accentuation (including *agogic*), articulation and instrument-specific variables. Challenges of the quantification problem begin with defining what is to be measured followed by selecting appropriate techniques to gather and compare measurements.

An important part of the research was to determine the ebb and flow of expressivity across an entire work rather than just on a localized basis. As will be seen in Chapter 6, considerable success was achieved in examining whether skilled performances have common traits in this respect.

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<sup>3</sup> Another application may be to develop ways of comparing *sonifications* of time series data as envisaged within *The Sonification Handbook*, ed. by Thomas Hermann, Andy Hunt and John Neuhoﬀ (Berlin: Logos Verlag Berlin GmbH, 2011). Musical sonifications have wide applications in areas as varied as bond trading and sports performance.

<sup>4</sup> Repp, Bruno, 'The Dynamics of Expressive Piano Performance: Schumann's "Träümerei" Revisited', *Journal of the Acoustical Society of America*, 100.1 (1996), 641–50.

## Structure of this dissertation

Chapter 1 positions the dissertation in the context of related research and publications. It reviews the foundations of MPS, the depth and breadth of scholarly research that underpins it and the key theories and prior scholarship that inform this research including cross-disciplinary studies and innovative technical methods. It distinguishes the ontological basis for studying musical performances as art, as against focussing on musical scores. Since Schoenberg's *Phantasy* is the target of the analysis, there is some consideration of the aesthetics and reception of twelve-tone music.

The characteristics of music recordings are presented in Chapter 2—highlighting differences from live performances together with challenges that arise by using recordings as research sources.

The main purpose of Chapter 3 is to discuss the musical structures and salient scholarly studies of the *Phantasy*. It is not an extensive formal analysis of the *Phantasy*. Instead, it examines some different ways of considering the work's structures, which will be used later to consider how changes in expressive playing can represent and communicate structures.

Chapter 4 presents the performance analysis model, which I developed specifically for this research project and named *Saxify*. This model is intended to be generally applicable to music performances using multiple performance variables captured over time. It lays out an effective technique to capture measurements at fixed intervals, to convert those to a symbolic representation (which importantly leads to data compression), to generate a *performance norm* which is a conceptual 'average performance' and to quantify dissimilarity between a performance and that norm. This measure is the degree of dissimilarity between *performance fingerprints*.

Validating the model, as described in Chapter 5, uses recordings of Chopin's Mazurkas that were previously analysed by researchers at the AHRC Research Centre for the History and Analysis of Recorded Music (CHARM). The CHARM research website preserves both their experimental results as well as data extracted from hundreds of recordings and papers and conference proceedings that detail their techniques.

A case study is presented in Chapter 6 that applies the *Saxify* model to Schoenberg's *Phantasy* and tests several hypotheses about expressivity in performing this work.

Chapter 7 discusses the conclusions that arise from this research project, its limitations and some implications for future research. It is clear that *Saxify* can deliver useful results but it is also evident that there is significant scope to extend it. Specifically, the software might usefully be packaged into a mobile toolkit for general use in music performance research. Computer software aspects of the approach may be significantly enhanced in future research by parameterising all the variable components rather than modifying the software each time in order to add new variables.

My research has benefited from prior qualifications and work. I hold a piano teaching diploma (ARIAM) from the Royal Irish Academy of Music and continue to teach a number of diploma-level students. I hold both BA and MA degrees in music from the Open University, and a MSc degree in statistics and computer science from Trinity College Dublin (TCD). I also make vain attempts to play cello.



# CHAPTER 1 | FOUNDATIONS

This chapter establishes the tradition of scholarly research into musical performance, and reviews the background literature and theoretical bases that inform this dissertation.

## 1.1 Scores

Score-based analysis delivers limited insights into the real-time decision-making and communication processes that must occur as a musical performance unfolds. This dissertation is predicated on making a shift from the view of musical *works*, embodied in *scores*, to an alternative view that treats *performances* as art. Performances are the instantiations of musical art in time. Achieving deeper insights into performances may benefit from a multidisciplinary approach to quantify characteristics of performance style: a combination of deep musical knowledge, computational techniques and appropriate analysis. This is not in any way to suggest that aesthetic principles or alternative musicological approaches have nothing to offer MPS. The present research demonstrates that it is feasible to evaluate variables of performed music within a standards-based, quantitative model that can reach verifiable conclusions about performing style. Those conclusions may then be used to inform further research, pedagogy, and performances.

During the eighteenth-century European Enlightenment, aesthetic valuations of artistic endeavours are seen to be influenced by an increased interest in the ancient disciplines of oratory and rhetoric. Performance arts generally acquire an aesthetic ranking above that of the fine arts. In respect of music, typically composers had been employees of a patron, creating one-off compositions for specific occasions, under long-standing systems of secular and clerical patronage. Performances of earlier large-scale compositions depended on musical forces available in the widespread tradition of aristocratic patronage. Musical works of scale were ‘entertainment and celebration’.<sup>1</sup> This required collaborative efforts between composers, poets, visual artists and performers of different types.<sup>2</sup> However, any significant occasions of music

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<sup>1</sup> Tia DeNora, ‘Musical Patronage and Social Change in Beethoven’s Vienna’, *American Journal of Sociology*, 97.2 (1991), 311.

<sup>2</sup> Eamon O Doherty, ‘Music for Church and Court: Influences on Marco Da Gagliano at Florence and Mantua’ (MA Dissertation, Open University, 2008), 6.

consumption by Viennese aristocratic patrons, using private orchestras, are not for sharing with ‘social inferiors’.<sup>3</sup> Patronage gradually shifts from court and church to concert hall such that composers ‘break out on their own’, acquire music publishers that take commercial risks, creating music for mass consumption rather than for one-off performances.<sup>4</sup> Performers (usually travelling ones) had previously been more highly esteemed than either composers or musical creations. This tradition is gradually followed by a ‘social broadening of musical patronage’.<sup>5</sup> Priorities substantially reverse, yet again, during the nineteenth century, shifting emphasis towards an esteemed view of musical high-art conceived as (a) the primacy of scores as art and (b) independent *works* rather than performances. Analysis of *works* is to become separated from any performances of them, as typified by many quasi-mathematical analyses of modern music constructed during the second half of the twentieth century.<sup>6</sup> Components or models for formal music analysis (forms and structures, melodies, harmonies, rhythms) are not so concerned with how music sounds nor even with ‘individual pieces of music’.<sup>7</sup>

The notion persists, in the practice of executing score analyses independently of any sonic realisations, that musical works exist as pure art objects, whether or not they ever be performed: in Frith’s terminology this comprises the *objectification* of music.<sup>8</sup> There has been criticism that purely technical analyses of music do not adequately guide performances. Edgar refers to mathematical, ‘technical analysis’ of music as being ‘irrelevant to the creative and original powers of the artist’.<sup>9</sup> This view, that analysis

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<sup>3</sup> Tia DeNora, *Ibid.*, 328.

<sup>4</sup> Sibel Karakelle, ‘The Carriers of the Enlightenment: Mozart and Rousseau in the 18th Century Europe’, *Humanity and Social Sciences Journal*, 2.1 (2007), 25.

<sup>5</sup> Tia DeNora, *Ibid.*, 310.

<sup>6</sup> Allen Forte, ‘A Theory of Set-Complexes for Music’, *Journal of Music Theory*, 8 (1964), 136–39+141+140+142–83; also Allen Forte, ‘Sets and Nonsets in Schoenberg’s Atonal Music’, *Perspectives of New Music*, 11 (1972), 43–64; also Milton Babbitt, ‘Responses: A First Approximation’, *Perspectives of New Music*, 14 no. 2/ 15 no. 1 (1976), 3–23; also David Lewin, ‘Transformational Techniques in Atonal and Other Music Theories’, *Perspectives of New Music*, 21.1/2 (1982), 312–71; see Ricoeur’s discussion of the loss of rhetoric in the 1800s and Plato’s fear of its power in Paul Ricoeur, *The Rule of Metaphor: The Creation of Meaning in Language (La Metaphore Vive)*, trans. by Robert Czerny, Kathleen McLaughlin, and John Costello, English Edition (London: Routledge Classics, 2003), 8.

<sup>7</sup> Eric Clarke, ‘Mind the Gap: Formal Structures and Psychological Processes in Music’, *Contemporary Music Review*, 3.1 (1989), 3.

<sup>8</sup> Simon Frith, ‘Music and Identity’, in *Questions of Cultural Identity*, ed. by Stuart Hall and Paul du Gay (London: Sage Publications, 2003), 108–27.

<sup>9</sup> Edgar, Andrew, ‘Adorno and Musical Analysis’, *The Journal of Aesthetics and Art Criticism*, 57 (1999), 439–49. Also see Nicholas Cook, ‘Perception: A Perspective from Music Theory’, in *Musical Perceptions*, ed. by Rita Aiello and John Sloboda (New York: Oxford University Press, 1994), 79.

must support performances, is echoed by Preda-Ulita.<sup>10</sup> She favours a more ‘applied analysis’ as something that offers real performance recommendations. She repeats Schenker’s warning against too-literal interpretations of any composer’s score indications.<sup>11</sup> This may be contrasted with, among others, purely technical set theory techniques that offer limited guidance towards making music actually happen, accepting that such techniques may help to uncover non-obvious details, and relationships, that may be relevant to performances.<sup>12</sup> This is surely a telling indication that purely technical analysis does not possess sufficient pedagogical value on its own: regarding Webern, Perry agrees that ‘What it cannot do is give this repertoire a performing presence. Like Schoenberg, Webern occupies for the most part a special niche, that of a composer better known to scholars than to performers’.<sup>13</sup>

## 1.2 Musicology and musical performance

A relatively newfound focus on researching performances may be explained partially in terms of a post-modern ‘construction of subjectivity’ that has made a ‘the embodiment of music in performance inevitable’.<sup>14</sup> Rink advocates a new performance-oriented approach to studying musical structures ‘taking into account the creative role of performers in giving music shape’ and determining structures from what he terms the ‘narrative of their performance’.<sup>15</sup> He perceives the significance for listening to what performers do rather than having a theoretical structure prescribing performance. Research into music performances may augment the comprehension of music, at least as much as do formal analyses of musical scores. One consistent problem, in certain types of formal music analysis, is with highly technical analyses that present complex obscurity with an ‘air of the secret society’.<sup>16</sup>

Adorno accepted the ontological view that musical works exist independently of performance instantiations. He argued that music, like visual arts, represents ‘social

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<sup>10</sup> Preda-Ulita, Anca, ‘Analysis and Performance: Views on the Performers’ Musical Awareness’, *Bulletin of the Transilvania (sic) University of Brasov, Performing Arts*, 8 (2015), 83.

<sup>11</sup> Preda-Ulita, *Ibid.*, 84.

<sup>12</sup> Forte, Allen, *The Structure of Atonal Music* (New Haven and London: Yale University Press, 1973).

<sup>13</sup> Perry, Jeffrey, ‘Review of Allen Forte, *The Atonal Music of Anton Webern*’, *MTO*, 2000, ¶6.10.

<sup>14</sup> Mine Dogantan-Dack, ‘Models and Metaphors: Exploring Musical Performance’, in *Systems Research in the Arts* (Baden-Baden: International Institute for Advanced Studies, 2006), 83–91.

<sup>15</sup> John Rink, ‘The Interpretative Shaping of Music Performance Research’, *Empirical Musicology Review*, 8.2 (2013), 120.

<sup>16</sup> Joseph Straus, ‘A Primer for Atonal Set Theory’, *College Music Symposium*, 31 (1991), 1.

problems through its own material and according to its own formal laws'.<sup>17</sup> Some modern scholarship argues that musicology must do some things differently, meaning it should moderate its focus 'from the score to the performance'.<sup>18</sup> Performances, particularly recordings, have gradually become valid candidates for scholarly research.<sup>19</sup> Historical recordings are recognized to be important sources for understanding how performers have mediated musical works to listeners in musical, artistic and social contexts. They form a comprehensive body of research materials that may be targets of repeat, replicable, accurate studies.

Performing style may change substantially within narrow periods of time. Symphonic sound from the first quarter of the twentieth century, to take one example, is quite different from later periods. This is in part due to the more primitive recording systems in the earlier period but also to different attitudes to the sounds being created. Historically, music had been restricted at various times to concert hall, church or court. A combination of influences mandated improvements in performing standards within the twentieth century: these included public tastes, broadcast media, physical dissemination of recordings, access to a worldwide performance market, and latterly consumption anywhere, any time, on portable devices. The paying public dominates what concert halls will programme.

There are performance variables that change continuously in time throughout any performance, including pitch, playing speed (*tempo*), attack rate, loudness (*dynamics*) and width of string vibrato – variables which might be related to visual analogies such as brightening/darkening, colour, hue, physical scale, or to our human spatial sense of movement.<sup>20</sup> There are instrument-specific variables such as bow force, breathing, tonguing and fingering details. There are also variables, such as tuning temperament or

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<sup>17</sup> Quoted by Cook from Theodor Adorno, 'On the Social Situation of Music', *Telos* 35 (1978) as noted in Peter Martin, *Sounds and Society: Themes in the Sociology of Music* (Manchester: Manchester University Press, 1995), 100. See Cook's argument in Nicholas Cook, *The Schenker Project: Culture, Race and Music Theory in Fin-de-Siecle Vienna* (New York: Oxford University Press, 2007), 314.

<sup>18</sup> Daniel Leech-Wilkinson, 'Compositions, Scores, Performances, Meanings', *Music Theory Online (MTO)*, 18.1 (2012), 2/17.

<sup>19</sup> There is a related argument, not discussed herein, that performers, conductors and ensembles, presently rank even above composers in importance. See Hermann Danuser, 'Execution, Interpretation, Performance: The History of a Terminological Conflict', in *Experimental Affinities in Music*, ed. by Paolo DeAssis (Leuven: Leuven University Press, 2016), 186.

<sup>20</sup> Zohar Eitan and Roni Granot, 'How Music Moves: Musical Variables and Listeners' Images of Motion', *Music Perception*, 23 (2006), 221.

tuning, that do not usually vary during one performance (*scordatura* tuning, as in Bach's Cello Suite No. 5 BWV 1011 being one notable counter-example).

There are hypotheses as to how musicians manipulate tempo and loudness, to expressive effect, in a performance.<sup>21</sup> It is notable that tempo and loudness typically account for only 10–18% of the variance in listener ratings of performances, such that other variables, possibly very elusive ones, must have much greater impact even if the impact of any individual variable is small.<sup>22</sup> This is one justification for seeking to extend the nature and number of variables to be considered, even if the remaining 80–90% of variance is contributed by an aggregate of many small influences. Geringer, citing several other researchers, determined that musicians perceive the magnitude of dynamic change as being less than non-musicians do. He also refers to the characteristic that 'crescendos are more frequent and longer lasting than decrescendos' as being a directional asymmetry of performance.<sup>23</sup>

It shall later be demonstrated how the *Saxify* approach proposed herein is generally applicable to performance variables that can be measured, including continuous rates of change (rather than just absolute values) — even if some are very difficult to perceive aurally. This requires techniques to estimate these types of variable and consideration as to how changing interactions of such complex measures might indicate style evolution. Music performance has many characteristics in common with *Complex Systems*, not least because the descriptive variables of performance 'interact in a dynamic way and therefore change over time'.<sup>24</sup> This merits additional research into which and how specific combinations of variables impact comparisons between recorded performances.

To the extent that MPS falls within an empirical tradition, it draws upon a wide range of techniques to investigate quantitative hypotheses.<sup>25</sup> The musician developing an expressive performance does not set out to deliver a sequence of random, temporal events onto which expressivity is layered as a final step. They are engaged in a highly

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<sup>21</sup> Langner, Jörg, and Werner Goebel, 'Visualizing Expressive Performance in Tempo-Loudness Space', ed. by Tim Crawford and Lorna Gibson, *Computer Music Journal*, 27 (2003), 69–83, 80–83.

<sup>22</sup> Gabrielsson, *Ibid.*, 226.

<sup>23</sup> John Geringer, 'Continuous Loudness Judgements of Dynamics in Recorded Music Excerpts', *Journal of Research in Music Education*, 43.1, 23.

<sup>24</sup> Dorottya Fabian, *A Musicology of Performance: Theory and Method based on Bach's Solos for Violin*, (<http://www.openbookpublishers.com>: OpenBook Publishers, 2015), p. 274, <http://dx.doi.org/10.11647/>.

<sup>25</sup> Nicholas Cook and Eric Clarke, 'What Is Empirical Musicology', in *Empirical Musicology: Aims, Methods, Prospects*, ed. by Cook Nicholas and Clarke Eric (New York: OUP, 2004), 3.

structured process with four key stages that loop backwards and forwards as necessary: (1) exploration, (2) mastering specific technical difficulties, (3) constructing an expressive interpretation, and (4) constructing an expressive performance.<sup>26</sup> The two earlier phases are concerned with general understanding, the latter two with communication and how individual players manage emotional state as a performance unfolds in time.<sup>27</sup>

Several researchers propose that expressivity communicates musical structure at some level. They leave room for many factors to be considered—‘temporal cues’ being always significant.<sup>28</sup> An additive theory of expressivity supposes that expressive intensity is an addition to a ‘neutral performance’.<sup>29</sup> Such a model supposes that there can be a class of baseline performances that exist before expressivity is added as an additional layer. At the lowest level, expressivity is a way to ‘highlight certain musical events’ whether they are phrase boundaries, harmonic structures/cadences, or higher-level boundaries such as section breaks.<sup>30</sup> Experienced musicians learn to separate their own emotional state from the emotional requirements of performance delivery. Research has shown that individual performers can deliver similar expressivity in performances that are widely separated in time.<sup>31</sup> This dissertation will demonstrate that several performances by Rudolf Kolisch, of the *Phantasy*, show close similarities in expressivity even with different pianists and spread over two decades.

### 1.3 Science

MPS is a field of research that demands innovation in how to perceive and measure underlying performance factors. Tempo, dynamics and interactions thereof, are still valid subjects of enquiry but there are many other possibilities. This dissertation

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<sup>26</sup> Anemone Van Zijl and John Sloboda, ‘Performers’ Experienced Emotions in the Construction of Expressive Musical Performance: An Exploratory Investigation’, *Psychology of Music*, 39.2 (2010), 208–211.

<sup>27</sup> Van Zijl and Sloboda, *Ibid.*, 213.

<sup>28</sup> Timothy Walker, ‘Instrumental Differences in Characteristics of Expressive Musical Performance’ (PhD dissertation, 2004), 11.

<sup>29</sup> Sergio Canazza, Giovanni de Poli and others, ‘Modeling and Control of Expressiveness in Music Performance’, *Proc IEEE*, 92.4 (2004), 690.

<sup>30</sup> Bryony Buck, Jennifer MacRitchie and Nicholas Bailey, ‘The Interpretative Shaping of Embodied Musical Structure in Piano Performance’, *Empirical Musicology Review*, 8 (2013), 94, see also Walker, *Ibid.*, (p. 7). and also Angelo Martingo, ‘Communicating Music: Structure, Cognition and Expression’, in *Proceedings of the International Symposium on MPS 2013* (presented at the International Symposium on Performance S, Brussels: Association Europeene des Conservatoires, 2013), 827.

<sup>31</sup> L. Henry Shaffer, ‘Timing in Solo and Duet Piano Performances’, *Quarterly Journal of Experimental Psychology*, 36.4 (1984), 425.

chooses to examine them in a new way and also to establish the relative importance that second-order performance variables—such as the rate of change of dynamics, and the rate of acceleration—have among the factors that may discriminate performances from one another.<sup>32</sup>

There are precedents for applying a scientific approach to the benefit of musicology. Scientific method involves firstly proposing a hypothesis (usually of no difference or no change). The researcher designs repeatable experiments and makes rigorous attempts to falsify the hypothesis. In defining the *scientific method*, Karl Popper distinguished between verifiability and falsifiability.<sup>33</sup> This dissertation has been structured around a set of experiments that rely upon Popper's approach. To verify is to amass supporting evidence; to falsify is to prove a hypothesis wrong.

Pythagoras viewed music as a branch of mathematics. Eminent scientists including Fourier, Helmholtz, Leibnitz, Euler and Kepler contributed to the related sciences of acoustics, harmonics and the physics of musical sound.<sup>34</sup> Schilling published his *Encyclopaedia of All the Musical Sciences* in 1840.<sup>35</sup> Use of computational techniques in research means that musicology may 'extend its visibility, especially outside the humanities'.<sup>36</sup> At the same time, musicology must continue to look beyond purely computational tools, at the broadest views of perception and cognition, since computation alone cannot provide a holistic view of musical performance.<sup>37</sup> The body of modern scholarly literature on MPS largely takes on formal scientific approaches, yet the field also encompasses many other specialities.

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<sup>32</sup> Velocity, which is distance per unit time, is a vector having direction and magnitude. In musical terms velocity is tempo, with fixed direction, and normally measured in number of beats per minute, or per second. Acceleration is the rate of positive change in tempo per unit time. Deceleration is the equivalent rate of negative change. Acceleration can be conceptualized as a tangent to a tempo curve – its value is the slope of the tangent (therefore of the curve) at a point. An analogous explanation pertains to loudness and the rate of change of loudness.

<sup>33</sup> Karl Popper, *The Logic of Scientific Discovery*, translated from the original German *Logik der Forschung* (1935), Vienna: Verlag von Julius Springer (London: Routledge, 2005), 18.

<sup>34</sup> Eduardo Calle, 'Music as a Branch of Mathematics: 2007 Winter Institute' (Miami Dade College, 2007), 3.

<sup>35</sup> Gustav Schilling, *Encyclopädie Der Gesammten Musikalischen Wissenschaften: Oder Universal-Lexicon Der Tonkunst* (Stuttgart: Verlag den Franz Heinrich Kohler, 1840) <https://archive.org/stream/encyclopdiender06byuschi#page/4/mode/1up>, Accessed:13 January 2017.

<sup>36</sup> Henkjan Honing, 'The Comeback of Systematic Musicology: New Empiricism and the Cognitive Revolution', *Tijdschrift Voor Musiektheorie*, 9.3 (2004), 243.

<sup>37</sup> Marc Leman and Antonio Camurri, 'Understanding Musical Expressiveness Using Interactive Multimedia Platforms', ed. by Richard Parncutt, *Musicae Scientiae (Special Issue on Interdisciplinary Musicology)*, 2006, 209.

Major MPS advances took place from the early 1990s which were accompanied by an increased focus on computational and quantitative techniques, not all of which may have proved useful in pushing the boundaries of research. Dedicated departments have been established, along with focussed research centres, symposia and conferences.<sup>38</sup> Much of the relevant research has taken place outside traditional, gravitational centres of musicology, with Northern and Eastern Europe leading the way early in the 1980s. Important research on other continents, including Konečni's at the psychoaesthetic laboratory in University of California, worked to translate purely aesthetic claims for music theory into testable hypotheses. Konečni's team had considerable success in demonstrating the incorrectness of supposedly objective claims such as: the importance of tonal closure, awareness of repetition, and 'perceptual significance of Schoenbergian operations on the tone row'.<sup>39</sup> In prior research, Konečni had reordered movements of Beethoven sonatas and quartets, Bach's *Goldberg Variations*, and Mozart's Symphony No. 40 in G minor K.550. The research used panels of music undergraduates and non-musical groups to test whether the reordered works were musically acceptable. In his words, 'no empirical support was obtained ... that either global or local structure ... influenced the subjects' ratings of the masterpieces on an array of hedonic, emotion-related, and cognitive judgement scales'.<sup>40</sup> These are important results because they demonstrate that an aesthetic value proposition in respect of a musical work, essentially a subjective judgement, may not represent the reality of listening experiences even for musically literate listeners. It is difficult to argue for or against Konečni's proposition that all aesthetic pronouncements may be converted to a testable form. This alone appears to offer scope for wider research in the field of MPS, recognising that he offers his proposition as something that may be applicable to all art forms.<sup>41</sup>

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<sup>38</sup> See Centre for Performance Science at the Royal College of Music, Centre for Music and Science at University of Cambridge, Trinity Laban Conservatoire of Music and Dance, Stockholm Royal Institute of Technology.

<sup>39</sup> Vladimir Konečni, 'On Philosophical and Empirical Aesthetics', in *Proceedings of Person. Color. Nature. Music 2005* (presented at Person. Color. Nature. Music, Daugavpils, Latvia, 2005), 48.

<sup>40</sup> Vladimir Konečni and Mitchell Karno, 'Empirical Investigations of the Hedonic and Emotional Affects of Musical Structure', in *Jahrbuch Der Deutschen Gesellschaft Fur Musikpsychologie*, ed. by Klaus-Ernst Behne, Günter Kleinen, and Helga de la Motte-Haber (Wilhelmshaven: Florian Noetzel GmbH, 1994), 11, 135).

<sup>41</sup> Konečni and Karno, 11, 119+121.



## 1.4 Recordings

Musical scholarship now accepts audio recordings as valid primary research sources.<sup>42</sup> Historical recordings are fundamentally important to understanding how performers have mediated musical works to listeners in varied musical, artistic and social contexts and at different times. Among other uses, historical recordings may be used to compare performance ‘norms of one age’ against ‘idiosyncrasies or anachronisms of another’.<sup>43</sup> Unlike live concerts, the reception model for recorded music is typically private and almost infinitely repeatable. This means that any recording may be subjected to repeated analysis, by different researchers. Music, in all its forms, is now an ever-present element of life whether disseminated in digital (or analogue) format, broadcasted, delivered on one of many internet channels, or even streamed directly by satellite. This demonstrates a trend towards extreme personalisation of the listening experience. Until relatively recent times, music was by necessity a shared experience. Today music may be experienced, in solitude, as a set of personalized listening choices both in terms of what is listened to and whether this means complete works of music. Increasingly, choices are delivered in streamed electronic formats since physical distribution (mainly CD) is in global decline.<sup>44</sup> This may be demonstrated by looking into some sample statistics for classical music, the decline across all formats already appearing terminal. For example, April 2015 classical music sales statistics from Nielsen were so low as to be negligible. The highest selling album in the second week of April 2015—CDs and downloads combined—was of Andrea Boccelli with fewer than 400 units sold. The next two in rank order, still above only 300 units sold, were the Benedictines of Mary and a Hilary Hahn Mozart concerto recording. Below these, there was no classical disc whose sales exceeded 200 units.<sup>45</sup> By 2016, Nielsen was stating that no classical recording (on CD or streaming) sold more than 100 units in the USA in the prior year. The share of listeners to classical music played by the top fifty US radio stations is relatively stable

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<sup>42</sup> Dorrotya Fabian and Emery Schubert, ‘Baroque Expressiveness and Stylishness in Three Recordings of the D Minor Sarabanda for Solo Violin (BWV 1004) by J. S. Bach’, *Music Performance Research*, 3 (2009), 36–55.

<sup>43</sup> Eric Clarke, ‘Listening to Performance’, in *Musical Performance: A Guide to Understanding*, ed. by John Rink (Cambridge: CUP, 2002), 194.

<sup>44</sup> On-demand streaming was up 54% over 2013 and 164 billion track streams were played by music consumers (all genres) in 2014. Source: Nielsen Entertainment, <http://variety.com/2015/music/news/album-sales-continue-decline-music-streaming-rises-in-2014-1201394229/>, Accessed: 17 January 2017. See a significant example of music streaming services at Spotify <https://www.spotify.com/ie/>, Accessed: 21 January 2016.

<sup>45</sup> Source: Nielsen Entertainment, (<http://slippedisc.com/2015/04/classical-record-sales-just-keep-on-falling/>), Accessed: 22 January 2016.

but stands at only 1.5% of the national audience.<sup>46</sup> Digital downloads (e.g. iTunes) have declined dramatically in favour of streaming services for all genres including classical music—UK download revenues dropped by 33% in 2015 from a peak in 2013 while streamed track revenues more than doubled in the same period.<sup>47</sup>

The costs of producing new classical recordings now exceed the likely revenues from physical distribution. The long-term implications of all these statistical trends surely indicate that access to classical recordings must rely, in future, on libraries or other collections, but that very few new recordings will be made. There seems likely to be no commercial markets that will justify the costs of recording, manufacturing and distributing physical media. The store of historic recordings is a hugely valuable resource both for listening and researching. Yet the vulnerability of online resources may be very high. A music-sharing website (Myspace) admits to losing twelve years of music—a loss that may total 50 million tracks by 14 million artists—due to human error during a server upgrade.<sup>48</sup>

## 1.5 Recordings or live performances

This dissertation does not argue for the primacy of either live or recorded performances (whether studio or live), despite an argument that recordings do ‘not represent the performer as an equal partner in the production of knowledge and in the formation of the dominant discourse’.<sup>49</sup> Given the practical and legal difficulties of gathering data for live performances of a single work, and the resource that historical recordings comprise, there may be no choice in this matter if performance is the subject of research. Stravinsky, writing of the value of recordings, believed that later recordings of any composer’s works should be ignored: the only reliable interpretation of a composer’s intentions being ‘preferably the very first’ recordings.<sup>50</sup>

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<sup>46</sup> Source: <https://classicalmusicrising.org/about/press-room/facts-figures/>, Accessed: 20 June 2017.

<sup>47</sup> Source: ERM Entertainment Monitor cited at <http://www.angrymobmusic.com/global-music-markets-preferred-music-formats-genres/>, Accessed: 20 August 2017.

<sup>48</sup> See report at <https://www.bbc.com/news/technology-47610936>, Accessed: March 18, 2019.

<sup>49</sup> Mine Dogantan-Dack, ‘The Art of Research in Live Music Performance’, *Music Performance Review*, 5 (2012), 39.

<sup>50</sup> Robert Fink, ‘Rigorous (♩ = 126): “The Rite of Spring” and the Forging of a Modernist Performing Style’, *Journal of the American Musicological Society*, 52.2 (1999), 303. It is, however, notable that that Stravinsky frequently changed his opinions on fundamental topics—see an exploration in Leonora Saavedra, ‘Stravinsky Speaks to the Spanish Speaking World’, in *Stravinsky and His World*, ed. by Tamara Levitz (Princeton: Princeton University Press, 2013), 177.

Due to the nature of production processes that involve splicing incremental and partial performances, recordings are not synonymous with live performances. However, one basic assumption underpinning this dissertation is that recordings may be treated substantively as *proxies* for prevailing styles of performance. This assumption justifies why multiple recordings of a single work, over an extended period, can comprise a valid source of data on performing style. They represent some contemporaneous views as to what is an acceptable style that may be validated by a marketplace of musicians, record producers and listeners that *consume* recordings in Adorno's sense, referring to music, of the 'masochistic mass culture that is the necessary manifestation of almighty production itself'.<sup>51</sup> If producers are too far out-of-line with what listeners will consume, recording income will decline. Recordings are discussed more fully in Chapter 2.

## 1.6 Twelve-tone music

For twelve-tone music the performer's role, in interpreting a composer's intentions and deriving structural information that can be communicated, is in some ways more significant than may otherwise be the case in performances of tonal art music since listeners, unless very skilled, are highly dependent on the performer's interpretative abilities. Intensity develops in the sonic presentation alone, not from expectation inherited from a historic canon. A researcher might anticipate, as a result, that more extremes in expressivity ought to be detected, since the performer must innovate communication within a complex context of 'abrupt shifts in high and low frequencies, uneven rhythm' and often scant melody.<sup>52</sup> It should be accepted that the opposite may be the case: either some music may inherently command less expressivity in delivery or a composer may demand this.

## 1.7 Formal models

A quantitative approach to music performance must be subject to an overall model that can be explained and whose results can be replicated. Several scholars have explored the importance of MPS research for the activities that are commonly involved in

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<sup>51</sup> Theodor Adorno, *Essays on Music*, ed. by Richard Leppert, trans. by Susan Gillespie (Berkeley: University of California Press, 2002), 297.

<sup>52</sup> Martin Lindauer, *The Expressiveness of Perceptual Experience: Physiognomy Reconsidered* (Amsterdam: John Benjamins Publishing, 2013), 57–58.

planning performances, strategies for rehearsal and pedagogical directions for learning and memorisation.<sup>53</sup> Quite how to decide on appropriate science is a key issue. Cook, a firm supporter of MPS as a discipline, does caution against adopting ‘inappropriate scientific paradigms’ and misunderstanding scientific methods. He suggests broadening the field of empirical MPS, and directs researchers away from a primary focus on the piano and on nineteenth-century monophony.<sup>54</sup>

European musicology is sometimes defined in terms of three distinct disciplines. These are ‘ethnomusicology, historical musicology and systematic musicology’.<sup>55</sup> Of the three, systematic musicology, being the empirical heart of MPS, focuses on measuring how music persists as a repeatable, yet varying phenomenon and is most relevant to this dissertation. MPS is broad in scope and multidisciplinary by nature, encompassing at least parts of the realms of psychology, sociology, music technology, information systems, data science, acoustics and cultural theory. It is not so concerned with ‘specific manifestations of music: pieces, styles and traditions’ but rather with such aspects of performance as acoustics, social context, player (and listener) emotion, and communication.<sup>56</sup> MPS researchers apply computational modelling and statistics to computer performances to ground scientific hypotheses in empirical observations.<sup>57</sup> They may examine how a performer's understanding of musical structures is communicated to listeners – even if Konečni and Karno’s research (see §1.3 above) suggests that there are limits to the success of such communication.<sup>58</sup> They may ultimately seek to construct new hypotheses and theories on the basis of observation and analysis: the new, data-driven approach that is almost a reversal of the scientific method.<sup>59</sup>

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<sup>53</sup> Yvette Sullivan and Robert Cantwell, ‘The Planning Behaviours of Musicians Engaging Traditional and Non-Traditional Scores’, *Psychology of Music*, 27.2 (1999), 245–66.

<sup>54</sup> Nicholas Cook, ‘Implications for Music Studies’, in *Expressiveness in Music Performance: Empirical Approaches across Styles and Cultures*, ed. by Dorottya Fabian, Renee Timmers and Emery Schubert (Oxford: OUP, 2014), 334.

<sup>55</sup> Richard Parncutt, ‘Systematic Musicology and the History and Future of Western Musical Scholarship’, *Journal of Interdisciplinary Music Studies*, 1.1 (2007), 4.

<sup>56</sup> Parncutt, *Ibid.*, 3.

<sup>57</sup> Parncutt, *Ibid.*, 4.

<sup>58</sup> Henkjan Honing, ‘On the Growing Role of Observation, Formalization and Experimental Method in Musicology’, *Empirical Musicology Review*, 1.1 (2006), 2–6, <http://hdl.handle.net/1811/21901>; also see Konečni and Karno, *Ibid.*, 135.

<sup>59</sup> Personal email communication from Michael Brodie, Research Scientist, CASIL at Massachusetts Institute of Technology - ‘The Scope of Data Science’, 25 July 2017.

Research, across a wide range of disciplines, served for a time to make systematic musicology appear, in Leman's words, a 'stolen discipline'. His fears were that growth in the number of computation-, neuroscience- and engineering-focussed researchers overwhelmed many traditional musicology departments after 2000. Eventually researchers came to recognise that 'transdisciplinary' viewpoints may contribute substantively to music research and ultimately enrich those other disciplines.<sup>60</sup> American theorists of the 1950s and later, notably including Milton Babbitt, Allen Forte and David Lewin, had argued that 'analysis should be a means ... by which perception is expanded in creatively unforeseen ways' but it must usually be focussed on understanding structures.<sup>61</sup> Yet it seems from Konečni's research (see §1.3 above) that performance alone may not be able to deliver that understanding. The idea that structural understanding is relevant to performance was very important to the central figures of the Second Viennese School's performance practice, including violinist Rudolf Kolisch, composers Anton Webern and Alban Berg, pianist Edward Steuermann and Schoenberg's composition student Erwin Stein. Performances by the so-called Schoenberg circle made much of the structural features of compositions, but perhaps not in an expected way. They did not ordinarily seek to 'bring out' structures that might become apparent from analysis of the score. Instead, they sought ways of performing that could richly realize acoustic or instrumental phenomena lying 'latent beneath the musical surface'.<sup>62</sup> Their performances tended to eschew abstract analytical features in favour of mechanical or sonic stimuli. Pianist Eduard Steuermann, who executed many performances of Schoenberg's works, believed that a performer's role is to 'bring the dead signs on the paper back to life': the musical text and its inherent signs point the way towards optimal performances.<sup>63</sup> In other words, the composer has laid down a template for performance. The performer must formulate an understanding of the

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<sup>60</sup> Marc Leman, 'Systematic Musicology at the Crossroads of Modern Music Research', in *Systematic and Comparative Musicology: Concepts, Methods, Findings*, ed. by Albrecht Schneider, Hamburger Jahrbuch Für Musikwissenschaft (Frankfurt: Peter Lang, 2008), 93. Also see Moreno Andreatta, 'Mathematica est exercitium musicae: la recherche mathémusicale et ses interactions avec les autres disciplines', (Habilitation dissertation, University of Strasbourg, 2010), 1, <https://tel.archives-ouvertes.fr/tel-00526432/document>, Accessed: 16 June 2018. Trans. from French by Eamon O Doherty, 48.

<sup>61</sup> Nicholas Cook, 'Border Crossings: A Commentary on Henkjan Honing's "On the Growing Role of Observation, Formalization and Experimental Method in Musicology"', *Empirical Musicology Review*, 1.1 (2006), 8.

<sup>62</sup> Alfred Cramer, 'The Schoenberg Circle's Utopian Performance Practice' (presented at the Annual Meeting of the American Musicological Society, Baltimore, Maryland, 1996). §1. <http://pages.pomona.edu/~awc04747/AMS96/AMS96.html>, Accessed: 20 June 2014.

<sup>63</sup> Gunther Schuller and Eduard Steuermann, 'A Conversation with Steuermann', *Perspectives of New Music*, 3.1 (1964), 34.

composer's intended sounds and rely upon the specific sign system to regenerate the art. Steuermann talked about Schoenbergian interpretation in 'mainly instrumental terms that made little or no reference to personal expression'.<sup>64</sup> There was a profound emphasis on using very precise instrumental techniques ahead of any formal analysis. This included tuning temperament. Both Kolisch and Steuermann favoured standard equal temperament tuning, which is quite unnatural to string players.<sup>65</sup> Rubato was employed, not as a standalone expressive device, but to 'demarcate formal sections' at a phrase level. It should be noted that Schoenberg, influenced by Paul Hindemith's move away from expressionism and Gustav Hartlaub's *Neue Sachlichkeit* ('New Objectivity') movement, disliked 'exaggerated rubato' even if he considered Hartlaub's movement too radical in 'its attempt to deny any expression from musical performance'.<sup>66</sup> This may exhibit in the trend in recorded performances of the *Phantasy* towards a reduction in expressive variability.

In Hailey's words, scholarship has 'recently begun to accommodate a range of music ... governed by organizational principles such as timbre and rhythm'.<sup>67</sup> The capability to incorporate alternative aesthetic frameworks into musicology, to include all types of modern popular music, is a quite recent phenomenon. Many techniques have been applied to popular music recordings such as detecting significant shifts in compositional style, alternative harmonic structures, chord changes and timbres. Musicology has, until very recently, lacked the types of data needed to conduct extensive studies based on a

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<sup>64</sup> Cramer, *Ibid.*, §1.

<sup>65</sup> In equal temperament tuning, all semitones are separated by the same frequency amount. Pianos use a *modified equal temperament* where the ratios between semitones, especially at the low and high ends, are made larger than the theoretical values. This is because there is a tendency for the overtone series of harmonics of each note on a piano to run sharp (termed *inharmonic*). One solution to this problem is to tune octaves slightly wider than theory predicts, using the *Railsback Curve*. Violinists debate whether to tune strings in perfect 5ths (Well Temperament) or precisely in Equal Temperament, as usually taught to them, but unless playing extensively with piano do not normally tune precisely to the modified piano intonation. Expressive intonation for violin (and other strings) attempts to raise sharps such that leading notes, for example, are closer to the tonic. Pablo Casals, cellist, and Carl Flesch, violinist, both used the term *expressive intonation* to signal the importance of a performer selecting the precise and possibly varying, interval depending on musical context, perhaps more so in minor keys. See Robert Young, 'Inharmonicity of Plain Wire Piano Strings', *The Journal of the Acoustical Society of America*, 24 (1952), 267, <http://dx.doi.org/http://dx.doi.org/10.1121/1.1906888>; See also Mónica Sánchez, 'The Expressive Intonation in Violin Performance', in *Proceedings of 9th International Conference on Music Perception and Cognition* (presented at the 9th International Conference on Music Perception and Cognition, Alma Mater Studiorum University of Bologna, 2006), 491.

<sup>66</sup> Avior Byron, 'Pierrot Lunaire in Studio and Broadcast: Sprechstimme, Tempo and Character', *Journal for the Society for Musicology in Ireland*, 2 (2006), 83.

<sup>67</sup> Christopher Hailey, 'Schoenberg and the Canon: An Evolving Heritage', in *Constructive Dissonance: Arnold Schoenberg and the Transformations of Twentieth Century Culture*, ed. by Juliane Brand and Christopher Hailey (Berkeley: University of California Press, 1997), 170.

scientific rather than a cultural approach.<sup>68</sup> Music has been brought very late to the types of practice-led research that are common in psychology, biology and social science.<sup>69</sup>

Some sample statistics illustrate growth in research activity around music performances and MPS. Gabrielsson conducted a significant literature survey on publication activity in several areas of performance research.<sup>70</sup> He classified approximately 500 peer-reviewed journal papers, articles and dissertations on performance generated in the early 1990s. By 1995, that had increased to 600. Within less than ten years there were 800. Another view of levels of research activity, on music as performance practice, can be gleaned from conference proceedings. The International Symposium on Performance Science 2007 proceedings published 68 papers.<sup>71</sup> For International Symposium on Performance Science 2013, the number had increased to 144.<sup>72</sup> By International Symposium on Performance Science 2015<sup>73</sup> there were 150 papers, posters and workshops.<sup>74</sup> The Performance Studies Network (PSN 2011) conference at the University of Cambridge hosted 68 lectures, papers and panels, PSN 2013 (Cambridge) hosted 70, PSN 2014 (Cambridge) 71 and PSN 2016 (Bath Spa) 73.

## 1.8 Performance: a primary focus of research

Over the most recent thirty years, performances have increasingly gained in importance in musicological research.<sup>75</sup> There are several key questions that may be posed in this regard: is it possible objectively to determine from recorded sound alone if and how

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<sup>68</sup> Matthias Mauch and others, 'The Evolution of Popular Music: USA 1960-2010', *Royal Society Open Science*, 2015, 1, <http://dx.doi.org/http://dx.doi.org/10.1098/rsos.150081>.

<sup>69</sup> Mine Dogantan-Dack, 'Artistic Research in Classical Music Performance: Truth and Politics', in *Proceedings of the 8th Symposium on Systems Research in the Arts* (presented at the 8th Symposium on Systems Research in the Arts, London, 2006), 31.

<sup>70</sup> Alf Gabrielsson, 'Music performance research at the Millenium', *Psychology of Music*, 31.3 (2003), 221–72.

<sup>71</sup> *Proceedings of the International Symposium on Performance Science 2007*, ed. by Aaron Williamon and Daniela Coimbra (Brussels: European Association of Conservatoires (AEC), 2007).

<sup>72</sup> *Proceedings of the International Symposium on Performance Science 2013*, ed. by Aaron Williamon and Werner Goebbl (Brussels: European Association of Conservatoires (AEC), 2013). Also see relevant, innovative academic programmes such as the Bachelor of Science in Physics and Music Performance degree, from October 2018. This is a joint Imperial College and Royal College of Music initiative.

<sup>73</sup> Which I attended thanks to a bursary from the Anne Leahy Bursary fund.

<sup>74</sup> *Proceedings of the International Symposium on Performance Science 2015*, ed. by Aaron Williamon and Masanobu Miura (Kyoto, Japan: Ryokoku University, 2015).

<sup>75</sup> John Rink, 'The State of Play in Performance Studies', in *The Music Practitioner: Research for the Music Performer, Teacher and Listener*, ed. by Jane Davidson (Aldershot: Ashgate Publishing, 2004), 37.

performances of any work might change over time? How can performances be compared? What may we learn about one performer at different times?

The model that is proposed herein starts with the consideration that an individual musical performance unfolds in time: each musical variable traces its own series of events. The overall performance, as well as individual parts of it, is subject to a set of style factors that may relate to, perhaps, the player(s) and their musical schooling, the context of the performance, prevailing performance or socio-cultural norms and the specific musical work being performed.

A quantitative approach to performance may be positioned to deal with data that unfold over time in terms of individual performances and with the totality of performances of a single work.<sup>76</sup> The combination is a *Performance Style*, which describes, in a summary way, how certain performances are executed. It may be related to a school of performance, or to a specific performer, to a country or tradition, or to a range of other influences that concern instantiation for a genre and a socio-cultural environment. Performing musicians tend to specialize in one, or few, genres adapting performance styles for specific performances.

For present purposes, a *Compositional Style* describes music at some arbitrary level of classification (such as classical, baroque, jazz or pop) in relational to a sign system, rule system, grammar and underlying semiotics. According to Franco Fabri, in his attempts to define the term *musical genre*, Compositional Styles are essentially music event-centric.<sup>77</sup> They are not necessarily score-based, since musics, such as jazz, do not rely, for purposes of transmission, exclusively on scores.<sup>78</sup> Inevitably, a Compositional Style will influence musicians in the execution and technical characteristics of its music performances. Continuing, Fabbri defines a music *genre* as ‘a set of musical events (real or possible) whose course is governed by a definite set of socially accepted rules’. He relates the types of musical events within a genre to a definite set of performance and

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<sup>76</sup> It should not claim to be universally applicable: John Cage’s 4’33” is not amenable to the model envisaged herein since total silence in one performance is unlikely to provide a useful basis for comparison with another (unless random audience sounds be considered a part of the performance). This composition is more a work of philosophy than of music.

<sup>77</sup> Franco Fabri, ‘A Theory of Musical Genres: Two Applications’, in *Popular Music Perspectives*, ed. by David Horn and Philip Tagg (presented at the First International Conference on Popular Music Studies, Amsterdam: Göteborg and Exeter: International Association for the Study of Popular Music, 1981), 52.

<sup>78</sup> ‘At best, however, an account of jazz works in terms of scores must be incomplete. It is incomplete since improvisation is a common feature of many jazz performances.’ James Young and Carl Matheson, ‘The Metaphysics of jazz’, *The Journal of Aesthetics and Art Criticism*, 58.2 (2000), 125.



social rules, such as for an ethnic music, that may be real or virtual. It should not be assumed that performers located within such a classification system are aware of any such specific classification. Performers of and listeners to an ethnic music are unlikely to continuously recognize their position as part of any taxonomy of musical genres or types, even if all cultural cases ‘need reference to a framework of cultural norms’.<sup>79</sup> Performance style for twelve-tone music, where listener acceptance has surely been quite limited, may be conditioned by a more determined performer analysis since there are fewer exemplars to draw upon.

Schoenberg’s twelve-tone compositional style fell from favour very soon after his death. Boulez’s *Schoenberg is Dead* was first published in 1952 in an attempt to proclaim the power and austere, serialist compositional style of Webern as the prime replacement for Schoenberg. Many of Schoenberg’s earlier compositions were firmly in the late-nineteenth century Romantic tradition. It was Boulez’s stated intention to sever links to music that could possibly evoke the nineteenth century with ‘reminiscences of a dead world’.<sup>80</sup>

Earliest performers of the *Phantasy*, including Koldofsky and Menuhin, received their formative schooling before, or near, the turn of the twentieth century. Their performance traditions were based on the Western Art Music (WAM) canon, early twentieth- and some late nineteenth-century performance practice and explorations of tonality by, among others, Mahler, Debussy, Strauss and Brahms. How far could younger performers develop new pathways from initial explorations, during Schoenberg’s lifetime, to craft new performance styles for twelve-tone music and its successors? Regarding styles changing over time, it seems plausible to suggest that artists establish their individual interpretation of a piece early in their performing career and retain significant features of those earlier interpretations for long periods.<sup>81</sup> It shall be shown that this is borne out by recordings of the *Phantasy*. Professional performers hone expressive interpretations of works during rehearsals, including exact timings, such that repeated performances exhibit close similarities, even over extended periods.

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<sup>79</sup> Franco Fabri quoting Umberto Eco, ‘Browsing Music Spaces: Categories and the Musical Mind.’ (presented at the IASPM, UK, 1999).

<sup>80</sup> Pierre Boulez, ‘Schoenberg Is “Dead”’, in *Notes of an Apprenticeship*, trans. by Herbert Weinstock (New York: Alfred A. Knoff, 1968), 273.

<sup>81</sup> Alistair Sung and Dorottya Fabian, ‘Variety in Performance: A Comparative Analysis of Recorded Performances of Bach’s Sixth Suite for Solo Cello from 1961 to 1998’, *Empirical Musicology Review*, 6.1 (2011), 20–42.

Rehearsal is not just about memorizing notes, it is also about deciding and re-creating an expressive interpretation, phrasing and shaping.<sup>82</sup> Analyses of Musical Instrument Digital Interface (MIDI) data, the most precise evidence after piano rolls, have been used to show that performers substantially retain individually distinct tempo/dynamics characteristics, none more so than at phrase boundaries, particularly when delivering a *diminuendo*.<sup>83</sup>

Musical performance style may properly be viewed as a *generalizing phenomenon* such that its evolution may be drawn out over a long period and its specifics may be too fine-grained to apply in any substantive way.<sup>84</sup> Style needs to be distinguished from expressivity since one may exist without the other. Scruton argues for considering whether ‘poor performances’ are those that fail to match listeners’ expectations within a compositional style. Perhaps there is an objective aesthetic attaching to each musical work, that may be paired with the composer’s intentions ‘on the basis of historical documents or compositional styles and aesthetics’.<sup>85</sup> Modern art musics pose a performance ‘challenge to theories of expressivity’ since there appears to be no guarantee that simply replicating existing models of performance in a new music that ‘lacks an expressive code, or possesses one that ordinary listeners cannot read’ is sufficient or suitable.<sup>86</sup>

There is a huge range of individual choices to be made by a musician, some of which are:

- Should they replicate a composer’s (or editor’s) markings as to dynamics, tempo or special effects such as *glissandi*?
- If a composer indicates a metronome marking on a section, to what extent may a performer deviate from the marking, treating the marking as a guide, or deviate in respect of some other details within the section?
- How should a performer develop micro-tempi, dynamics, inter-movement

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<sup>82</sup> Jane Davidson and James Good, ‘Social and Musical Co-Ordination between Members of a String Quartet: An Exploratory Study’, *Psychology of Music*, 30 (2002), 18.

<sup>83</sup> Jennifer MacRitchie, Bryony Buck and Nicholas Bailey, ‘Gestural Communications: Linking Multimodal Analysis of Performance to Perception of Musical Structure’ (presented at the International Symposium on MPS, Utrecht: AEC, 2009), 587.

<sup>84</sup> Leech-Wilkinson, *Ibid.*, 797.

<sup>85</sup> Roger Scruton, *The Aesthetics of Music* (Oxford: OUP, 1997), 376; see also Fabian and Schubert, *Ibid.*, 37.

<sup>86</sup> Elina Packalen, ‘Musical Feelings and Atonal Music’, *Postgraduate Journal of Aesthetics*, 2.2 (2005), 98.

timings and the treatment of silences?

- Since a performance, using Ingarden's terminology, is an *intentional object*, a performer might be expected to adhere to conventions which may be mandated by a score, ritual, or social convention.<sup>87</sup> But which parts of a convention may be altered? How? By whom? For example, a listener might expect the actual notes to be played as notated, and in the indicated sequence. A counter example is the jazz convention of applying a performer-determined degree of swing to notated runs of quavers. This mirrors Baroque performance conventions of *notes inégales*.
- And what is pitch when one considers temperament and the differences between a fixed-pitch instrument (piano) and variable-pitch (violin)? Bach transcribed many pieces from one instrument to another without compromising on technical execution. For example, he rewrote his Violin Concerto in A minor, BWV 1041 as the Clavier Concerto in G minor, BWV 1058. His Violin Concerto in E major, BWV 1042 was the model for his Harpsichord Concerto in D major, BWV 1054).

Expressivity, at its simplest, may be considered a judicious balancing of the contents of a score with 'what the score leaves unspecified' – it is at the performer's choice to deviate from the composer's explicit directions, assuming some norms may be obtained from the hierarchical structure.<sup>88</sup>

Intensity changes in music have been considered to be additive in the sense that an increase in value for one variable is usually accompanied by an increase in value for another – ultimately balanced by a release of tension. This has led to questions about how tempo impacts upon dynamics and, by implication, whether tempo variability affects dynamic variability and whether pitch transformation affects dynamics or tempo. Eitan's research suggests that 'intensity is a cross-dimensional quality' and can co-associate 'perceived magnitudes in different sensory modes'.<sup>89</sup> The relationship between actual auditory stimuli and neural processes is complicated by further studies that show

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<sup>87</sup> Roman Ingarden, 'Essay 1 - The Musical Work', in *The Ontology of the Work of Art*, trans. by Raymond Meyer and John Goldthwait (Ohio: Ohio University Press, 1989), 93.

<sup>88</sup> Renee Timmers and Henkjan Honing, *Ibid.*, 4. This definition ignores jazz, any improvisations and generally any music that is not score-based.

<sup>89</sup> Zohar Eitan, 'Intensity and Cross-Dimensional Interaction in Music: Recent Research and Its Implications for Performance Studies' (presented at the Study day, Tel Aviv: Department of Musicology, 2005), 143.

the brain probably processes intensity as an ‘abstract concept’ rather than as a sensory stimulus.<sup>90</sup>

There has been minimal significant research undertaken to compare characteristics of *intensity* across multiple complete performances, although innovative alternate approaches have been developed for visualizing and comparing sections of recorded performances. Several studies have related an *arched convex* phrase shape (referring to a tendency for performance characteristics to increase to a maximum) to intensity increases along specific variables such as pitch, dynamics and texture where ‘intensification ... is followed by abatement’.<sup>91</sup> Eitan notes that emphasis is not always an issue of dynamics, offering the example of how articulation changes on harpsichord substitute for dynamic contrast.<sup>92</sup> Eitan and Granot suggest that intensity contours bear a relationship with structure and ‘shape’.<sup>93</sup> Listeners that experience a music performance may ‘associate musical gestures [...] (that) do share intensity contours’.<sup>94</sup> As early as 2004, Levitin *et al.* coined the terms *affective velocity* and *affective acceleration* to refer to the first and second derivatives of position within a musical performance with respect to time. They argued that continuous change is an instantaneous indicator of musical tension and release. Affective velocity is a performance technique that leads listeners towards a point of maximal tension, followed by release. Affective acceleration defines whether the path to maximal tension is driven ‘at a constant rate, at an increasing rate, or at a decreasing rate’.<sup>95</sup> This supports what Sloboda refers to as the impact of certain musical structures in the ‘creation and violation of expectancy’.<sup>96</sup> The significance of these studies is in relating higher-order derivatives to intensity, tension and emotional response.

For present purposes, each recording (or segments thereof) will be considered in terms of point tempi and dynamics, as well as point acceleration rates and rate of change in

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<sup>90</sup> Eitan, *Ibid.*, 145.

<sup>91</sup> Eitan, *Ibid.*, 149.

<sup>92</sup> Eitan, *Ibid.*, 151.

<sup>93</sup> Zohar Eitan and Roni Granot, ‘Intensity Changes and Perceived Similarity: Inter-Parametric Analogies’, *Musicae Scientiae*, Discussion Forum, 4A (2007), 39.

<sup>94</sup> Eitan, *Ibid.*, 66.

<sup>95</sup> Daniel Levitin, Bradley Vines and Regina Nuzzo, ‘Quantifying Musical Dynamics: Analyzing Musical Emotion with Differential Calculus and Functional Data Objects’, in *Proceedings of the 8th International Conference on Music Perception & Cognition*, ed. by S Lipscomb and others (Adelaide: Causal Productions, 2004), 450.

<sup>96</sup> John Sloboda, ‘Music Structure and Emotional Response: Some Empirical Findings’, *Psychology of Music*, 19 (1991), 120.

sound pressure levels. Many other variables might be chosen for inclusion using the same overall approach. For example, the shifting harmonic makeup of sequential pitches might be modelled by wrapping frequency values into bins containing the sum of magnitudes from corresponding bins in all octaves.<sup>97</sup> Each bin's value at a beat point would then form a separate performance data point. This could be a useful technique, for example, in modelling string or wind intonation on a continuous basis, notwithstanding the need to capture, integrate and interpret other relevant data.

In considering research into expressivity, there seems to have been an inevitable draw towards temporal phenomena more than any other aspect of performance.<sup>98</sup> Expressive timing on a micro scale is not independent of global tempi measured across larger-scale structures. As tempo increases, the proportional increase in long inter-onset intervals (IOIs) is less than short ones. The reverse occurs generally for tempo decrease. Much work has been done with MIDI recordings on the study of tempo invariance where determining factors such as key pressure and velocity may be precisely calculated and normalized for comparison by adjusting for the corresponding score note types.<sup>99</sup> With non-MIDI recordings, the measurement interval must be noted at a convenient time-interval, IOI being more difficult to calculate automatically due to limitations of the medium. Consideration of tempo is complicated by the components that make it up—random noise (being deviations in the range 10-100ms) and intentional expressive timing (which may vary up to 50% of notated durations).<sup>100</sup> Shaffer and Todd found that pianists attempt to communicate hierarchical structure by slowing down at 'points of stability' although noting that this may not be effective in practice.<sup>101</sup> The conclusion reached was that professional musicians develop a very precise way of generating an overall timing pulse: rubato instances, far from being an arbitrary 'whim ... are the outcome of coded decisions of interpretation'.<sup>102</sup>

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<sup>97</sup> This approach defines frequency *bins* over twelve pitch classes, such that (for example) Bb in all octaves is assigned to one pitch class and may in principle include subdivisions of microtones. The primary harmonics that determine each bin make up the chromagram.

<sup>98</sup> Mine Dogantan-Dack, 'Models and Metaphors: Exploring Musical Performance', in *Systems Research in the Arts* (Baden-Baden: International Institute for Advanced Studies, 2006), 88.

<sup>99</sup> Bruno Repp, 'Quantitative Effects of Global Tempo on Expressive Timing in Music Performance: Some Perceptual Evidence', 40+50.

<sup>100</sup> Peter Desain and Henkjan Honing, 'Tempo Curves Considered Harmful', *Contemporary Music Review*, 7 (1993), 129.

<sup>101</sup> Henry Shaffer and Neil Todd, 'The Interpretative Component in Musical Performance', in *Action and Perception in Rhythm and Music*, ed. by Alf Gabrielsson (Stockholm: Royal Swedish Academy of Music, 1987), 258.

<sup>102</sup> Shaffer and Todd, *Ibid.*, 269.

Recent years have seen new tools and techniques emerge that can deal with continuous responses from performers such as in measuring motion as a component of expressiveness.<sup>103</sup> Goebbl, Dixon and Schubert note difficulties with calculating absolute (as opposed to relative) dynamic levels and of aligning multiple performances for analytical purposes.<sup>104</sup>

## 1.9 Significant studies

There have been many studies in the philosophical tradition of MPS since the mid-eighteenth century. Cook, in defining expressivity, refers to ‘negotiated values of performance’ and to Adorno’s ‘zone of indeterminacy’.<sup>105</sup> If music is a communication between performer and listener, the performer is manipulating bundles of performance variables from instant to instant. These bundles can be perceived similarly to height contours on a map, or isobars of equal pressure (although in higher dimensions). A useful term suggested by Eitan and Granot is *intensity contour*.<sup>106</sup> One novel visualization technique for modelling tempo and loudness showed that pianists approach a phrase climax by increasing tempo first and dynamics later – a reversal of what was previously referred to as a characteristic of Daniel Barenboim’s playing style.<sup>107</sup> Techniques exist to examine expressive dynamics for single tones. But complex, simultaneous tones, coincident harmonics, phase relationships and amplitudes of fundamental frequencies make point determination of all ‘vertical’ components of dynamics very difficult.<sup>108</sup> It is even more complex where polyphonic voices have different, parallel, dynamic contours.

Raffman’s paper argues that formal, local structures, particularly in post-1950 music, are so incomprehensible, as to prevent feelings being engendered from listening to such music. She asks if ‘the literal understanding of a twelve-tone work [can] result from

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<sup>103</sup> Werner Goebbl, Simon Dixon and Emery Schubert, ‘Quantitative Methods: Motion Analysis, Audio Analysis and Continuous Response Techniques’, in *Expressiveness in Music Performance: Empirical Approaches across Styles and Cultures* (Oxford: OUP, 2014), 221.

<sup>104</sup> Goebbl, Dixon and Schubert, *Ibid.*, 226+231.

<sup>105</sup> Nicholas Cook, *Beyond the Score: Music as Performance* (Oxford: Oxford University Press, 2013), 273.

<sup>106</sup> Eitan and Granot, *Ibid.*, 39.

<sup>107</sup> Langner and Goebel, *Ibid.*, 12.

<sup>108</sup> Bruno Repp, ‘A Microcosm of Musical Expression: II. Quantitative Analysis of Pianists’ Dynamics in the Initial Measures of Chopin’s Etude in E Major’, *Journal of the Acoustical Society of America*, 105 (1999), 1972.

recovery of some property or properties other than its twelve-tone structure’?<sup>109</sup> It may be that other musical variables come to the fore when concepts of tonal centre or rhythmic familiarity are abandoned.

There are broadly three families of theory of expressivity as explained by Packalen, in his detailed critique of Raffman, in which he recognizes that concepts and theories of expressivity or ‘musical meaning’ may not translate freely, and for all time, to all musical styles:<sup>110</sup> (1) Cognitivists believe that music directly expresses emotions without reacting to it; (2) Arousalists believe feelings are ‘aroused’ by music, and (3) Symbolists find that music and emotions change somewhat in parallel to each other, due to some other influences, which Gabrielsson refers to as the ‘intimate relation between the structure of emotions and the structure of music’.<sup>111</sup>

Tempo, dynamics and phrasing were not notated in earliest music. Referring to Paddison’s translation of Adorno, these characteristic features needed to be ‘discovered from that which is not written’.<sup>112</sup> Expression is not something to be layered on at the last moment before performance, following all the stages of learning and practice. Possibly, it is not required at all in some types of music. For example, Heaton points to modern performances of Elliot Carter’s pointillist *GRA* as exhibiting a major emphasis on performing very accurate rhythms, yet with minimal expression.<sup>113</sup> Traditional analysis is less likely to help performance than discovering the ‘blind spot’ of such a work and the equilibrium that it ‘wants to make possible’.<sup>114</sup>

Desain and Honing deliver a thoughtful discussion on working with a professional pianist. They show that tempo curves can be usefully considered as discrete graphs that directly relate structure and timing.<sup>115</sup> Absolute pitch and loudness influence perception of absolute time intervals (shortening them at higher pitches and loudness levels).

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<sup>109</sup> Diana Raffman, ‘Is Twelve-Tone Music Artistically Defective?’, *Midwest Studies in Philosophy*, 27.1 (2003), 82.

<sup>110</sup> Packalen, *Ibid.*, 97. See also Raffman, *Ibid.*, 72+78. Also Peter Kivy, *An Introduction to a Philosophy of Music* (Oxford: OUP, 2002). And Laird Addis, *Of Mind and Music* (Ithaca: Cornell Press, 1999), see also Derek Matravers, *Art and Emotion* (Oxford: Clarendon Press, 1998).

<sup>111</sup> Alf Gabrielsson, ‘Expressive Intention and Performance’, in *The Psychology of Music*, ed. by Reinhart Steinberg (San Diego: Academic Press, 1999), 6.

<sup>112</sup> Theodor Adorno, ‘On the Problem of Musical Analysis’, trans. by Max Paddison, *Music Analysis*, 1.2 (1982), 172.

<sup>113</sup> Elliott Carter, *GRA for Clarinet Alone* (Boosey & Hawkes, 1993), HL.48005908. Composed in honour of Witold Lutoslawski; see also Heaton, *Ibid.*, 99–102.

<sup>114</sup> Theodor Adorno, ‘On the Problem of Musical Analysis’, trans. by Max Paddison, *Music Analysis*, 1.2 (1982), 172.

<sup>115</sup> Desain and Honing, *Ibid.*, 136.

Hevner measured musical expression by asking listeners to use an *adjective checklist* covering tempo, pitch, mode, harmony, rhythm and melody. His conclusions were later found to have statistical flaws that required a modified approach.<sup>116</sup> Several similar studies were commenced in the early 1980s of continuous evaluations of expressivity.<sup>117</sup> Expression in performance has even been theorized on the basis of a ‘Nature vs. Culture’ argument: nature being some inherent quality of a work that determines how it should be approached. A culture viewpoint is based on much greater freedom to experiment to ensure performances are ‘not just a monotonous and mechanical transcription’.<sup>118</sup>

Analysing intensity contours offers some possibility of gaining specific knowledge as to how listeners rate and rank performances. One hypothesis, rather than focussing on individual variables, is that performers simultaneously manipulate complex intensity contours both to accentuate/phrase locally, to mediate climaxes and present conclusions within an overall musical structure. In essence performers take on the responsibility to ‘manage expectation’.<sup>119</sup> Quite how listeners rate a performance may be considered in terms of how well intensity contours form and flow. There is a significant body of research into performances in terms of raw acoustic variables. There is also an important body of work on the social and cognitive psychologies of performance/performer interaction.<sup>120</sup> Recordings involve no element of risk or (subconscious) anticipation of failure since a record producer generally supersedes the performer in specifying the final output, which in any case may comprise multiple takes that are interlaced and overlapped to generate the producer’s desired effect. Live performances that heighten listener tension and expectancy must involve a greater degree of risk-taking. Any results can be eliminated in the production of a recording even where they are not performance errors as such. A skilled performer is mindful of the audience and manages to tame some elements of risk while heightening intensity

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<sup>116</sup> Kate Hevner, ‘Studies in Expressiveness of Music’, in *Music Teachers National Association Proceedings*, 1938, No. 39, 248.

<sup>117</sup> Goebel *et al.*, *Ibid.*, 229.

<sup>118</sup> Miguel Molina-Solana and Maarten Grachten, ‘Nature versus Culture in Ritardando Performances’, in *Proceedings Sixth Conference on Interdisciplinary Musicology*, 2010, 3–4.

<sup>119</sup> Marcus Pearce and Geraint Wiggins, ‘Auditory Expectation: The Information Dynamics of Music Perception and Cognition’, *Topics in Cognitive Science*, 4 (2012), 644.

<sup>120</sup> Q Zhang and Eduardo Miranda, ‘Evolving Expressive Music Performance through Interaction of Artificial Agent Performers’, in *Proceedings of the ECAL Workshop on Music and Artificial Life* (presented at the ECAL Workshop on Music and Artificial Life, Lisbon: MusicAL, 2007). See also Aaron Williamson and Jane Davidson, ‘Exploring Co-Performer Communication’, *Musicae Scientiae*, 6.1 (2002), 53–72.



appropriately. In order ‘for performers to discharge faithfully their aesthetic responsibilities, they must give considerable attention not only to their understanding of the composer’s demands and desires but also to the sensibilities of the audience’.<sup>121</sup> Of Gould it has been written that ‘there is no one in modern times who has departed so far from the norm and has still been able to make a living from performing and recording’.<sup>122</sup> According to Dunsby, Gould came eventually to believe that a live performance is musically false and, as did Schenker, that a musical work contains within itself its own *Meisterwerk* that dictates its optimal presentation.<sup>123</sup>

Modelling expressive timing and dynamics may oversimplify the linkages between structures and performances.<sup>124</sup> The capability to perceive structures requires a distinction between ‘random performance variability and that attributable to expressive intent’.<sup>125</sup> Timing appears to generate more analytical value, at the lowest levels of a musical structure, with intensity contributing more at higher levels.<sup>126</sup> Familiarity can lead to a sense of increased anticipation for listeners, higher in the case of tonal as opposed to atonal music, probably related to listeners’ ability to create a ‘mental representation (or schema) ... without overloading the working memory’.<sup>127</sup> In the case of recordings, no performance may stand as unique.<sup>128</sup> Listeners can distinguish the expressive timing of an original recording against a tempo-transformed version—supporting the significance of micro-tempi.<sup>129</sup> This is supported by statistically significant results that find tempo judgements to be more consistent where a listener empathizes with the musical performance.<sup>130</sup> More research is needed into how familiarity and expectation impact on structural understanding.

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<sup>121</sup> Eugene Narmour, *Explorations in Music, the Arts and Ideas: Essays in Honor of Leonard B. Meyer* (New York: Pendragon Press, 1988), 318.

<sup>122</sup> Leech-Wilkinson, ‘Compositions, Scores, Performances, Meanings’, §3.12.

<sup>123</sup> Jonathan Dunsby, ‘Performance and Analysis of Music’, *Music Analysis*, 8.1/2 (1989), 7–8.

<sup>124</sup> Neil Todd, ‘The Dynamics of Dynamics: A Model of Musical Expression’, *Journal of the Acoustical Society of America*, 91 (1992), 3549.

<sup>125</sup> Roger Kendall and Edward Carterette, ‘The Communication of Musical Expression’, *Music Perception*, 8.2 (1990), 129.

<sup>126</sup> Asmir Tobudic and Gerhard Widmer, ‘Playing Mozart Phrase by Phrase’, in *Proceedings of the 5th International Conference on Case-Based Reasoning* (presented at the 5th International Conference on Case-based Reasoning, Berlin: Springer, 2003), 552–66.

<sup>127</sup> Daynes, *Ibid.*, 469.

<sup>128</sup> Daynes, *Ibid.*, 470.

<sup>129</sup> Henkjan Honing, ‘Evidence for Tempo-Specific Timing in Music Using a Web-Based Experimental Setup’, *Journal of Experimental Psychology*, 32.3 (2006), 780–86.

<sup>130</sup> Eleni Lapidaki, ‘Consistency of Tempo Judgments as a Measure of Time Experience in Music’ (PhD dissertation, Northwestern University, 1996).

Studies of piano performance abound and include the difficult topic of how pianists create timbre.<sup>131</sup> The so-called *Horowitz Factor* postulates that there are deterministic explanations for why Horowitz's piano sound was so different. They may never be fully explained despite the power of modern Artificial Intelligence (AI) and machine learning models being applied to such difficult questions of performance, but it does not mean we should not research them.<sup>132</sup> It remains to be seen whether comparative studies of conventional pianos and high-quality digital instruments can provide useful results in this regard. Quite how pianists alter the timbre of their sound is not completely understood. A piano note is created percussively such that the performer is no longer in direct contact with the strings after striking the keyboard. There is firm evidence for an ability to create different interpretations, nuances of timbre and strikingly different senses of structure, even by one performer at different times.<sup>133</sup> Physical gestures by a pianist cannot modify the actual sound produced from the piano after striking a note. Yet different combinations of controlled muscle movements, from the fingertips all the way to the upper body at least, plus the preparation to strike the keys, are known to be the foundation of pianistic sound. Hammer velocity (the pure physical-acoustic approach) may be produced in more than one way – striking a note from above, or from an already established surface contact. Modern studies confirm that differences are not detectable (with statistical significance) unless the listener hears the finger strike. This noise occurs around 30ms before the note. Generally, harsher sounds are characterized as being struck, no matter the actual technique.<sup>134</sup> Empirical music studies, over the past thirty years, have applied a wide variety of statistical tests to identify variances and the factors that make them up. These studies vary from applying relatively straightforward tests, to sophisticated techniques such as *Principal Components Analysis* (PCA).<sup>135</sup> The latter is a dimensionality-reduction technique, transforming original variables into new *factors* that may prove very valuable in certain contexts. The nature of such techniques means dropping some information in order to make statements about underlying factors: however, interpreting results in respect of the transformed factors can be difficult.

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<sup>131</sup> Michel Bernays and Caroline Traube, 'Verbal Expression of Piano Timbre' (presented at the International Symposium on Performance Science 2011, Toronto, Canada, 2011), 303.

<sup>132</sup> Gerhard Widmer and others, 'In Search of the Horowitz Factor', *AI Magazine*, 24.3 (2003), 112.

<sup>133</sup> Leech-Wilkinson, 'Compositions, Scores, Performances, Meanings', §3.4, §3.5, §3.12. <http://mtosmt.org/issues/mt0.12.18.1/mt0.12.18.1.leech-wilkinson.php>, Accessed: 19 September 2015.

<sup>134</sup> Werner Goebel, Roberto Bresin and Alexander Galembo, 'Once Again: The Perception of Piano Touch and Tone. Can Touch Audibly Change Piano Sound Independently of Intensity?', in *Proceedings of the International Symposium on Musical Acoustics* (presented at the ISAM2004, Nara, Japan, 2004), 335.

<sup>135</sup> George Duntelman, *Principal Components Analysis, Quantitative Applications in the Social Sciences* (Thousand Oaks, CA: Sage Publications, 1989).

Formal Concept Analysis was applied to the detection of performance motifs in ten performances of Chopin's Etude Op. 10, No. 3.<sup>136</sup> So-called *Self Organising Maps* (SOM), have been suggested as another way to reduce the dimensionality of performance data and relate performances to each other. SOM is a useful technique for classifying (clustering) groups of input data that share similar characteristics.<sup>137</sup> Widmer and his research colleagues applied AI techniques to problems of grouping performances and of identifying performance patterns. Their study identified a characteristic pattern in Daniel Barenboim's performances of Mozart: an 'increase in loudness is followed by a slight tempo increase and followed by a decrease in loudness [...] with more or less constant tempo'.<sup>138</sup> Barenboim's control of independent performance variables is unusual among pianists in speeding up to points of maximum loudness. They had compared Barenboim's performances against other significant pianists of the twentieth century including Schiff, Uchida, and Horowitz. Langner and Goebbl came to similar conclusions and support the general contention that interaction between tempo and dynamics is not a simple faster-louder one.<sup>139</sup> They found that pianists typically increase tempo first, but that increases in loudness follow on. This means that most pianists tend to shape phrases such that they 'get slower but not faster at loudness maxima'. Similar studies have used 'performance alphabets' to represent commonly occurring features as alphabetic characters to aid in spotting patterns in repeating sequences.<sup>140</sup> Specific performer identification, applying kNN (*k nearest neighbour*) algorithms that group the melodic contour of a performance's note durations, was found to be superior to identification by human listeners, despite a quite high level of unreliability overall.<sup>141</sup> Such unreliability may be due to non-inclusion of

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<sup>136</sup> Neta Spiro, Nicholas Gold and John Rink, 'In Search of Motives: Identification of Repeated Patterns in Performances and Their Structural Contexts', in *Proceedings of ICoMCS December 2007* (presented at The Inaugural International Conference on Music Communication Science, Sydney, Australia: ed. Emery Schubert *et al.* (Sydney: ARC Research Network in Human Communication Science (HCSNet), 2007), 152-4, 2007), 154.

<sup>137</sup> Alex. Smola and S Vishwanathan, *Introduction to Machine Learning* (Cambridge: Cambridge University Press, 2008). See also Teuvo Kohonen, 'The Self Organising Map', *Proceedings of the IEEE*, 78.9 (1990), 1464-80.

<sup>138</sup> Widmer *et al.*, *Ibid.*, 124.

<sup>139</sup> I shall refer to this as the *Barenboim Effect*. See Langner and Goebbl, p. 12. Also see Ju-Lee Hong, 'An Empirical Analysis of Musical Expression in Recordings by Selected Cellists' (Masters Dissertation, Goldsmiths, University of London, 2014), 22 <http://research.gold.ac.uk/10156>, Accessed :18 August 2015.

<sup>140</sup> Widmer *et al.*, *Ibid.*, 125.

<sup>141</sup> Padraig Cunningham and Sarah Delany, *K-Nearest Neighbour Classifiers* (Dublin: UCD, 2007), p. 1. See also Miguel Molina-Solana, Josep Arcos and Emilia Gomez, 'Using Expressive Trends for Identifying Violin Performers', in *Proceedings of the 9th International Conference on Music Information Retrieval* (presented at the ISMIR 2008, Lulu.com: Youngmoo Kim, 2008), 499, <http://www.lulu.com/shop/douglas-turnbull-and-juan-pablo-bello-and-elaine-chew/proceedings-of-the->

factors that impact upon identification, pointing to the importance of considering multi-variate test scenarios for music data.

Musical performance involves both process and product. The process viewpoint arises from the time-based nature of music: performances unravel in time. The product viewpoint arises from encapsulating the entirety of a performance as something that occurs, may be captured on record and transacted in a commercial market. Performers transform musical works from a purely conceptual framework into a unique set of sonic objects that must be mediated to listeners with expressive effects and gestures. It is possible to treat a performance as a message communication in the sense that a performance is a set of information to be transmitted from sender to receiver. This message is itself independent of any possible semiotics arising from within the score unless the performer is capable firstly of understanding and secondly of communicating them. Performance style, in the abstract, is the collection of choices made by the performer in performance. The particular encoding of the complete message (the performance) contains the values of the variables of performance, whether measured or not. Decoding a specific performance message on the listener's part (interpreting the performance) seems to require the positive application of experience, education, context, socialisation and acculturation.

A further possible conclusion is that homogeneity of style in performance across multiple performances of a work, over extended time, may be directly due to availability of recordings. It seems that the preponderance of a few canonical performances available in recorded form, serve to standardize listener expectations.<sup>142</sup>

The following sub-sections §1.9.1 to §1.9.27 highlight the significant breadth and depth of MPS research and publications:

- 1.9.1 Early performance theory and pedagogy: The philosophical tradition of MPS is at least as old as the eighteenth century. There are important texts by early theorists and pedagogues as varied as Danuser, Riemann, Schilling, Quantz, Turk, Czerny, Crelle and

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9th-international-conference-on-music-information-retrieval-conference-edition/ebook/product-17432393.html.

<sup>142</sup> Dorottya Fabian, 'Is Diversity in Musical Performance Truly in Decline?: The Evidence of Sound Recordings', 21.

1.9.2 Systematic studies of performance: Early examples include Heinitz's 1920s timing comparisons of *Meistersinger* recordings, as well as very recent examples by Repp and Neubacker.<sup>144</sup> Ornoy conducted a laborious study of eight variables including: execution of double- and triple-stops, position shifts, rhythmic alterations and portamento.<sup>145</sup> During the 1930s, Carl Seashore's group had shown the relevance of quantitative techniques in relating musical silences (in this case) to the delivery of overall expressive effects in certain circumstances.<sup>146</sup> By the 1950s, Charles Seeger was seeking automated tools to improve his laboratory analyses of music recordings.<sup>147</sup> Friberg and Battel apply modern tools to note the importance, in the western art music performance tradition, of a combined tempo and dynamics arch that brings out phrasing structures in performance: the listener is intended to detect higher structural changes by more pronounced *ritardandi* at section endings.<sup>148</sup>

1.9.3 Listeners and visual perception: Dixon and colleagues developed a graphical technique

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<sup>143</sup> Guerino Mazzola, *Musical Performance: A Comprehensive Approach: Theory, Analytical Tools, and Case Studies* (Heidelberg: Springer, 2011), 30–31.

<sup>144</sup> Mazzola, *Ibid.*, 19.

<sup>145</sup> Ornoy, *Ibid.*, The tempo calculations were tedious to execute, using a stopwatch and metronome in the British National Sound Archive. Due to copyright restrictions he could not access these recordings elsewhere nor subject them to software analysis. 60% of the recorded performers, on recordings that feature significant tempo variation, were born prior to 1925. Ornoy conjectures that recordings would have had relatively little influence during their formative years. 75% of performers that feature stable tempi were born after 1925. He also found a more flexible approach to dotted rhythms in recordings made in or after the 1980s. And the use of 'swell' on a note – not typically used by performers born prior to 1933, was extensively used in the 1980s. The later period shows much freer use of dynamics, particularly on inner lines. One important factor in the transition of style is the increased influence of recordings as the marketplace expanded during the initial decades of the twentieth century. Ornoy chose 1925 as his point of reference – performers born before this date are less likely to have listened commonly to recordings than those born after. Additional factors suggested by Ornoy include 'school' or teacher and choice of score edition. Looking into performances of Bach's G minor Adagio, 75% of recordings exhibiting most stable tempi by their respective performers were born after 1925. Interestingly he found no connection between performance of dynamics and school/teacher. It seems unlikely that current technologies can provide a complete understanding of expressivity purely on the basis of computation. However, quantitative techniques are improving and models, such as are suggested in this dissertation, can help. MPS researchers have made significant progress since 2000 in developing tools for automatic tempo estimation (1) by treating 'frequency estimation and onset detection' as sub-problems and (2) by developing a deeper understanding of how to build systems to perform the estimations.

<sup>146</sup> His group demonstrated results such as 'inter-phrasal pauses are over four times as long as intra-phrasal pauses'. Cf. Carl Seashore, *Objective Analysis of Musical Performance* (Iowa: Iowa University Press, 1936), 116.

<sup>147</sup> David Cooper and Ian Sappiro, 'Ethnomusicology in the Laboratory: From the Tonometer to the Digital Melograph', *Ethnomusicology Forum*, 15.2 (2006), 106.

<sup>148</sup> Anders Friberg and Giovanni Battel, 'Structural Communication', in *The Science and Psychology of Music Performance: Creative Strategies for Teaching and Learning*, ed. by Richard Parncutt and G McPherson (New York: Oxford University Press, 2002), 201.

for visualizing performance characteristics as a ‘performance worm’ that relates tempo on the x-axis, dynamics on the y-axis, and colour intensity referring to the timebase of the performance (lighter means farther back in time).<sup>149</sup> Recent experiments with listener panels confirm that both novice and professional listeners discern visual and audio cues in rating music competition performances ‘against broad consensus that auditory information is core to the domain of music’.<sup>150</sup> Apart from suggesting an application in rating student performances, Dixon’s group discussed applying their techniques to analysis, and comparison, of famous performers. Many orchestras now conduct double-blind auditions to factor out gender, appearance and race from the hiring process.

- 1.9.4 Modern analysis of early performances: These have been captured on piano rolls, wax disks, opto-electronic recorders and later MIDI devices and computers. Using semiquavers as a measurement unit, when altering global tempo, several researchers found statistically significant differences in the degree of expressiveness of performances even though measurement at beat subdivisions is extremely difficult. Surprisingly, differences in expressiveness were more pronounced at both slow and fast tempi even for an individual performer. This led Repp to his ‘optimal tempo’ hypothesis: (1) a performance is less expressive when the performer feels uncomfortable having selected some non-optimal tempo and (2) there is always an optimal tempo for any piece of music that ‘permits the greatest expressive freedom’: the null hypothesis in this case being that ‘relational invariance holds’.<sup>151</sup>
- 1.9.5 Musical structures: Beran and Mazzola used statistical methods to verify three-way effects of metric, melodic and harmonic structures on performance.<sup>152</sup> They reached similar conclusions to Repp, using his specific data, but based on a completely different

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<sup>149</sup> Simon Dixon, Werner Goebbl and Gerhard Widmer, ‘The Performance Worm: Real Time Visualisation of Expression Based on Langner’s Tempo-Loudness Animation’, in *In Proceedings of the International Computer Music Conference* (Göteborg, 2002), §3.

<sup>150</sup> Chia-Jung Tsay, ‘Sight over Sound in the Judgment of Music Performance’, ed. by Dale Purves, *Proceedings of the National Academy of Sciences*, 119.26 (2012), 14583, <https://doi.org/10.1073/pnas.1221454110>.

<sup>151</sup> Bruno Repp, ‘Quantitative Effects of Global Tempo on Expressive Timing in Music Performance: Some Perceptual Evidence’, *Music Perception*, 13.1 (1995), 39–57.

<sup>152</sup> Jan Beran and Guerino Mazzola, ‘Analyzing Musical Structure and Performance—A Statistical Approach’, *Statistical Science*, 14.1 (1999), 47–79.

approach.<sup>153</sup> One interesting recommendation from their research is to consider using the logarithm of tempo rather than raw tempo data to focus on how performers control tempo in a relative rather than absolute way. This lateral thinking mirrors the proposal in this dissertation to analyze point rates of acceleration in tempo and dynamics.

- 1.9.6 Creative processes in performances: Originally studied in respect of improvisation, studies of musical performance creativity have focused more recently on interpretation, the role of teachers and of community.<sup>154</sup>
- 1.9.7 Pedagogy and performance: In setting out to perform a piece of music a performer could choose to take the pedagogical advice of a skilled teacher, listen to recordings or even trust their own intuition. Without any guidance to draw upon, even experience, it is difficult to warrant that any type of music could be successfully worked upon. Furthermore, it would seem reasonable to propose that a performer should always contribute something individual to interpretation. Efforts to personalize an artistic performance require some degree of analytical thought and positive decisions about the structure and character of the work. There has been considerable research into how musical performances may be assessed and ranked for examination purposes. There appear to be two major approaches, according to Thompson and Williamon: one being a holistic (or top-down) process, the other being based on specific performance elements that are assessed separately, then aggregated.<sup>155</sup> These authors caution against applying an over-detailed a set of measurement criteria since an experienced musician will be able to assess a performance in a more holistic way—somewhat like a chess grandmaster who applies pattern-matching skills rather than explicitly working all the possibilities on an iterative basis. Communication between pedagogues and researchers (while perhaps well-intentioned) may not necessarily be optimized.<sup>156</sup> Parncutt's study of post-secondary music institutions found that students were very poorly educated on aspects of the mechanics and acoustics of their instrument, the physics, physiology and

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<sup>153</sup> Bruno Repp, 'Diversity and Commonality in Music Performance: An Analysis of Timing Microstructure in Schumann's Träumerei', *Haskins Laboratory Status Report on Speech Research*, SR-111/112, 1992, 227–60.

<sup>154</sup> Isabelle Heroux, 'Creative Processes in the Shaping of a Musical Interpretation: A Study of Nine Professional Musicians', *Frontiers in Psychology*, 9:665, p. 2, <https://doi.org/10.3389/psyg.2018.00665>.

<sup>155</sup> Sam Thompson and Aaron Williamon, 'Evaluating Evaluation: Musical Performance Assessment as a Research Tool', *Music Perception*, 21.1 (2003), 23.

<sup>156</sup> Richard Parncutt, 'Can Researchers Help Artists? Music MPS research for Music Students', *Music MPS research*, 1.1 (2007), 3.

psychology of performance, and ‘explicit instruction on specific means of musical expression’.<sup>157</sup> This implies that students, at least in their early training and possibly later, may not receive enough information about how sound is created, how nuances of instrument-specific timbre are created, why trying different fingerings matters, how the presence/absence of individual notes in a chord can cause received sound to vary significantly, or how to improvise over an ostinato.<sup>158</sup> MPS is not something in the abstract. It has a pedagogical strength, not in persuading performers blindly to copy others, but in understanding which variables may best be manipulated and the likely outcomes. One aspiration of MPS research is to help students plan expressive strategies including appropriate variations in accents, vibrato, rubato and increased relative durations. Lewin considers that a performer relying on structural theories alone cannot generate a good performance independently of considering issues such as rhythm and pitch.<sup>159</sup> This reinforces Adorno's belief in repeated, educated listening as the only way to prepare for Schoenberg's style of composition.<sup>160</sup> Schoenberg held a fundamental view as to the importance of listening repeatedly to music, in advance of seeing a score or interpreting it.<sup>161</sup> Cook explains that it is as if Schoenberg anticipated that repeated listening could help subconsciously to detect musical structures, positioning understanding ‘not in the sense of an aesthetic response, but in terms of aural training’.<sup>162</sup>

- 1.9.8 Dedicated research centres, research groups and conferences: Initiatives were funded from the mid-1990s in the UK.<sup>163</sup> CHARM, at King's College ran until 2009 and was succeeded by the Centre for Musical Performance as Creative Practice (CMPCP) based at University of Cambridge in partnership with King's College, Royal Holloway and University of Oxford.<sup>164</sup> European centres were established, with medium-term funding,

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<sup>157</sup> Parncutt, *Ibid.*, 7.

<sup>158</sup> Parncutt, *Ibid.*, 9.

<sup>159</sup> David Lewin, ‘Transformational Techniques in Atonal and Other Music Theories’, *Perspectives of New Music*, 21 (1982), 361.

<sup>160</sup> Lydia Goehr, ‘Dissonant Works and the Listening Public’, in *The Cambridge Companion to Adorno*, ed. by Tom Huhn (Cambridge: Cambridge University Press, 2004), 229.

<sup>161</sup> Arnold Schoenberg, *Style and Idea*, ed. Leonard Stein trans. Leo Black (New York: St Martin's Press, 1975), 283.

<sup>162</sup> Nicholas Cook, *Music, Imagination and Culture* (Oxford: OUP, 1990), 228.

<sup>163</sup> The AHRC Research Centre for the Research and Analysis of Recorded Music (CHARM) website may be accessed at <http://www.charm.rhul.ac.uk/>, Accessed: 13 January 2016. This five-year project ended in 2009. It was succeeded for a further five years by the Centre for Musical Performance as Creative Practice (CMPCP) at <http://www.cmcp.ac.uk/>, Accessed: 13 January 2016.

<sup>164</sup> <http://www.cmcp.ac.uk/smip.html>, Accessed: 21 May 2014.



one at Jyväskylä in Finland using expertise from the music cognition group at University of Jyväskylä and another Brain and Music team at University of Helsinki's Department of Psychology. IPEM was founded at Ghent University in Belgium. There have been several international consortia of systematic musicologists spread across the universities of Cologne, Hamburg, Jyväskylä, Oslo and Ghent. The Centre for Performance Science (CPS) is an on-going research centre, founded in 2000 at London's Royal College of Music, as an 'internationally distinctive centre for research, teaching, and knowledge exchange in music performance science'.<sup>165</sup> Since the early 2000s, major MPS conferences have taken place at Montreal, Ghent, Tallin, Vienna, Thessaloniki and Graz.

- 1.9.9 Performance motifs: CHARM researchers developed techniques to identify *performance motifs* (repeated, and usually brief, patterns) in musical performances, which point to a relationship between those motifs and listener perceptions.<sup>166</sup> On the other hand, *compositional motifs* include harmonic, rhythmic or melodic components, that proceed on a process of augmentation, reduction and elimination.<sup>167</sup> *Performance motifs* are significant elements in the shaping of musical performances.
- 1.9.10 Musical gestures: Leman cites several studies into quantitative analysis of gestures in performance, emphasizing the importance to pedagogy of understanding links between physical gesture and musical content.<sup>168</sup>
- 1.9.11 Timing: There is evidence to support a tempo-specific timing hypothesis in that some relationship between a work's global tempi and minute timing variations can help a listener discriminate performances.<sup>169</sup> A study by Honing found that listeners to classical music could use expressive timing to detect transformation of global tempo. But in jazz, the opposite was found, possibly because listeners' tempo preferences

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<sup>165</sup> <http://www.rcm.ac.uk/research/researchareas/ps/>, Accessed: 13 Nov 2016.

<sup>166</sup> Neta Spiro and Nicholas Cook, 'Analysing Motif in Performance', *CHARM Newsletter*, AHRC, 5 (2009), 6.

<sup>167</sup> Jack Boss, 'Schoenberg's Op. 22 Radio Talk and Developing Variation in Atonal Music', *Music Theory Spectrum*, 14.2 (1992), 129.

<sup>168</sup> Marc Leman, 'The Need for a Cross-Cultural Empirical Musicology', *Empirical Musicology Review*, 8.1 (2013), 20.

<sup>169</sup> Henkjan Honing, 'Evidence for Tempo-Specific Timing in Music Using a Web-Based Experimental Setup', 785.

overrode their view of what is expressive in jazz performance.<sup>170</sup> It may be argued that recordings have tended to level out playing style and repress individual expression, by virtue of their availability and global spread. It does appear likely that authoritative performances made in the presence of, or under guidance of, its composer have a strong influence on early performances. The influences of the composer wane over time and performers alone determine the interpretation.<sup>171</sup>

1.9.12 Dimensionality reduction: In developing a model to cope with much larger musical works, it is essential to address the critical problem of dimensionality.<sup>172</sup> For music performances, it is necessary to take ‘slices’ across the multiple music variables at each point in time. The more of these to consider the greater the difficulties of analysis. Additional performance features, beyond tempo and dynamics, have been used by Ozaslan and Arcos to research guitar glissandi but the number of slices was small.<sup>173</sup> Most similar studies have used limited musical extracts to ensure that the ‘curse of dimensionality’ has not created a barrier to research.<sup>174</sup>

1.9.13 Advanced computer software: Early performance researchers achieved significant results using simply stopwatch and pencil.<sup>175</sup> Since at least the 1930s, scholars have researched systematically how performers deliver individual, expressive effects and how such effects operate at different levels to shape each performance and thereby communicate important structural concepts to listeners. Computer software can provide vital support in measuring and calculating. Computer software is widely applied to analysis and visualization of musical performances. The MISA project (Computer Modelling of Algebraic Structures in Music and Musicology: Cognitive, Philosophic,

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<sup>170</sup> Henkjan Honing, ‘Is Expressive Timing Relational Invariant under Tempo Transformation?’, *Psychology of Music*, 35.2 (2007), 283.

<sup>171</sup> Tina Huettneraich, ‘Three Case Studies in Twentieth Century Performance Practice’ (PhD dissertation, 2012), 164.

<sup>172</sup> Eamon O Doherty, ‘Music Performance Science: Analytics and Music Recordings’, in *Proceedings of the 2016 Music Technology Workshop: Establishing a Partnership Between Music Technology, Business Analytics and Industry in Ireland* (presented at the MustWorks16, UCD, Dublin, 2016), 56, [http://www.ucd.ie/t4cms/MusTWork\\_2016\\_Proceedings.pdf](http://www.ucd.ie/t4cms/MusTWork_2016_Proceedings.pdf).

<sup>173</sup> Tan Ozaslan and Josep Arcos, ‘Legato and Glissando Identification in Classical Guitar’, in *Proceedings of the 7th Sound and Music Computing Conference* (presented at the 7th Sound and Music Computing Conference, Barcelona, 2010), §67, 6.

<sup>174</sup> Eamonn Keogh and Abdullah Mueen, ‘Curse of Dimensionality’, ed. by Claude Sammut and Geoffrey Webb, *Encyclopedia of Machine Learning* (New York: Springer, 2010), 257–58.

<sup>175</sup> Bruno Nettl, *The Study of Ethnomusicology: Twenty-Nine Issues and Concepts* (Urbana: University of Illinois Press, 1983), 254.

and Epistemological Aspects) synthesized paradigms for software engineering, signal processing, specialist languages (e.g. OpenMusic), improvisation, symbol systems, man-machine interfaces, orchestration tools and sound synthesis.<sup>176</sup> Collaborators at Paris-based IRCAM continue to research the intersection between music and mathematics, *la recherche mathémusicale*, and to experiment with compositional models based on complex mathematics.

- 1.9.14 Pitch related to dynamics: Goebbl has demonstrated a strong relationship between pitch and dynamics, specifically in piano performances. This may be attributable to habitual and deliberate *melody lead* and asynchronous loudness variation between the right and left hands.<sup>177</sup> This is a common pianistic technique whereby the melody hand lags the other (and is usually louder) on average 30ms earlier than the accompanying hand.<sup>178</sup> Melody lead may also serve as an agogic mechanism in polyphonic parts.<sup>179</sup> Grachten and Widmer developed combinations of other variables, *basis functions*, to help predict performer-specific expressivity from score features.<sup>180</sup> This approach was not found to be substantially more successful than linear regression of the music variables. If expressive performance means deviation from a score, performers will differ as to how, where and what types of deviation they generate. The prevailing focus on monophonic samples is precisely due to limitations of available tools and difficulties of determining IOIs accurately where multiple simultaneous voices interfere.<sup>181</sup>

- 1.9.15 Listener preferences and ratings: Taruskin found that rhythmic flexibility, generally

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<sup>176</sup> Andreatta, *Ibid.*, 1. See also the MISA website at <http://recherche.ircam.fr/equipes/repmus/mamux/>, Accessed: 16 September 2016. OpenMusic is a Lisp-based visual programming tool for music representation developed at IRCAM by Carlos Agon, Gerard Assayag and Jean Bresson. <http://repmus.ircam.fr/openmusic/home> (accessed: August 15, 2016) and Carlos Agon, 'OpenMusic : un langage visuel pour la composition musicale assistée par ordinateur' (Doctoral dissertation, Université de Paris VI, 1998). It is worth noting that there is extensive MPS research literature published in languages other than English.

<sup>177</sup> Goebbl, Werner, 'Melody Lead in Piano Performance: Expressive Device or Artefact?', *The Journal of the Acoustical Society of America*, 110 (2001), 571.

<sup>178</sup> Werner Goebbl, *Ibid.*, 15–16. And see also Werner Goebbl, 'Skilled Piano Performance: Melody Lead Caused by Dynamic Differentiation', in *Proceedings of the 6th International Conference on Music Perception and Cognition* (presented at the 6th International Conference on Music Perception and Cognition, American Psychological Association, 2000).

<sup>179</sup> Palmer, *Ibid.*, 125. Contemporary software finds dense scoring difficult to manipulate.

<sup>180</sup> Maarten Grachten and Gerhard Widmer, 'Linear Basis Models for Prediction and Analysis of Musical Expression', *Journal of New Music Research*, 41.4 (2012), 414. Basis Functions are usually combined linearly, much as Fourier Analysis enables complex waveforms to be decomposed into sinusoidal functions.

<sup>181</sup> The intervals between the attack points of successive notes.

eschewed in Historically Informed Performances (HIP), is rated most highly across listener sensibilities.<sup>182</sup> Fabian proposed that improvements in *technical precision* means that performers generally take less risks and thereby provide less diversity of styles in performance.<sup>183</sup> A performance *Success* model found that the more flexible and articulated the performance, the more successful.<sup>184</sup> A *Stylishness* model explained performances in terms of flexibility of rhythm, detail of phrasing and straightness of tone. An *Expressiveness* model seeks out lightness of tone and flexible rhythm. Orchestral players in the period 1900 to 1950 were often equally soloists that brought, and maintained, very individual playing styles to their orchestras. This inevitably resulted in both poor ensemble coordination and inconsistencies in overall style.<sup>185</sup> These points are not to be taken as generalized criticisms of earlier period performance style, but as validations of the proposition that both style and overall performing quality can change within such a relatively short period as the post-1939 decade.<sup>186</sup> Of course there may never be just one interpretation of a piece of music that satisfies everyone. Every performance, unless of the simplest music, requires some analysis and interpretation of the meaning of the sounds. This involves a possibly infinite variety in shadings of tempo and other aspects of performance.<sup>187</sup>

1.9.16 Constructive ideas as to what performers might do differently over time: Starting with the basics of ‘Time, Frequency and Amplitude, but immediately following would come aspects of music-making that are likely to have been determined by naturally selected responses to sound’.<sup>188</sup>

1.9.17 Gesture and physical movement: Motion tracking systems have been applied to clarinet performances and sensor data with MIDI instruments to examine the relationship of

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<sup>182</sup> Richard Taruskin, ‘On Letting the Music Speak for Itself: Some Reflections on Musicology and Performance’, *The Journal of Musicology*, 1.3 (1982), 338–49.

<sup>183</sup> Dorottya Fabian, ‘Is Diversity in Musical Performance Truly in Decline? The Evidence of Sound Recordings’, *Context: A Journal of Music Research*, 31 (2006), 165.

<sup>184</sup> Fabian, Dorrotya, Emery Schubert, ‘Baroque Expressiveness and Stylishness in Three Recordings of the D Minor Sarabanda for Solo Violin (BWV 1004) by J. S. Bach’, *Music Performance Research*, 3 (2009), 36–55

<sup>185</sup> Robert Philip, *Early Recordings and Musical Style: Changing Tastes in Instrumental Performance 1900-1950* (Cambridge: Cambridge University Press, 1992), 179.

<sup>186</sup> Leech-Wilkinson, *Ibid.*, §7.

<sup>187</sup> Palmer, p. 119.

<sup>188</sup> Leech-Wilkinson, *Ibid.*, §7.

gesture and expressivity.<sup>189</sup>

- 1.9.18 Probabilistic predictive techniques: Create improvisations in the styles of various significant composers.<sup>190</sup> This type of work supplements Cope's explorations and syntheses of compositional styles.<sup>191</sup>
- 1.9.19 Recommender systems: High dimensionality typically leads to difficulties in categorizing music data automatically. Statistical techniques have been proposed to identify salient characteristics of performances – one goal being to find factors that might generate recommendations.<sup>192</sup> Such recommender (or recommendation) systems are becoming common, on the Internet, recommending music to listeners based on various factors including prior listening history, peer group preferences, purchase history and so forth.<sup>193</sup> Such systems need to be able to characterize salient features of a listener's preferred music and use those characteristics to match and recommend alternative choices. A disadvantage for a musically educated listener is that such systems may severely limit choices of performers, director or recording history. They are more tools of promotional marketing than aids to artistic choice.
- 1.9.20 Big Data: Welsh *et al.* attempted to match musical extracts to similar sounding popular songs in their database. Similarity was defined in terms of features across the feature space (including frequencies, volume, noise, tempo and tonality). They concluded that further research is required on better (non-Euclidean) similarity metrics as well as new

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<sup>189</sup> Marcelo Wanderley *et al.*, 'The Musical Significance of Clarinetists' Ancillary Gestures: An Exploration of the Field', *Journal of New Music Research*, 34.1 (2005), 97–113. Also Antonio Cammurri and others, 'EyesWeb - Toward Gesture and Affect Recognition in Interactive Dance and Music Systems', *Computer Music Journal*, 24.1 (2000), 57–59.

<sup>190</sup> Shlomo Dubnov, Gerard Assayag, Olivier Lartillot and Gill Bejerano, 'Using Machine-Learning Methods for Musical Style Modeling', *Computer*, 36.10 (2003), 73–74.

<sup>191</sup> David Cope, *Computers and Musical Style* (Madison, Wisconsin: A-R Editions, 1991).

<sup>192</sup> Dominikus Baur, Jennifer Büttgen and Andreas Butz, 'Listening Factors: A Large-Scale Principal Components Analysis of Long-Term Music Listening Histories' (presented at the CHI'12, Austin: ACM, 2012), 1273–76.

<sup>193</sup> Gediminas Adomavicius and Alexander Tuzhilin, 'Toward the Next Generation of Recommender Systems: A Survey of the State-of-the-Art and Possible Extensions', *IEEE Transactions on Knowledge and Data Engineering*, 17.6 (2005), 73).

algorithms for measurement.<sup>194</sup>

1.9.21 Composer-specific timing pulse: Clynes proposed a mechanism such that an expert performer will conceive a global pulse that determines the overall timing of a performance. Local adjustments may be made within the global pulse, typically for expressive delivery.<sup>195</sup> Repp challenged this proposition on several grounds including Clynes's supposed ability to discriminate very small timing differences appears to be beyond the abilities of even sophisticated musical listeners.<sup>196</sup> Clynes also proposed the controversial 'composer's pulse' theory, tested using a *sentograph*.<sup>197</sup> He suggested that each composer mandates a unique pattern of timing/accentuation. These patterns must be respected in performance in order to communicate the composer's intent. Individual performers will generate 'amplitude shapes' for individual tones: it is the sum of the whole of these individual effects that makes for the expressive nature of a performance, or even parts of it.<sup>198</sup> Repp argues that this theory is subject to 'an infinite regress, according to which only whole movements, or whole sonatas, or whole cycles of sonatas' can determine such a pulse and points out that Clynes modification of the supposed composers' pulse, under the influence of ornaments, destroys the integrity of the principle.<sup>199</sup> Clynes also found that the shapes of the amplitude curves alone, even after removing the effects of 'vibrato, timbre and of timbre variation', determine much of what is expressivity.<sup>200</sup> Moelants determined that there is a natural, preferred tempo for listeners, as opposed to Clynes's composer-oriented one, but it is an open question as to whether this is a physiological characteristic of humans or something inherent in

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<sup>194</sup> Matt Welsh and others, 'Querying Large Collections of Music for Similarity', (Advanced Research Projects Agency, 1999), §7.

<sup>195</sup> Manfred Clynes, 'Sources of Musical Meaning Tests of Composer's Pulses. [sic]', in *Proceedings of the First International Conference on Music Perception and Cognition* (presented at the First International Conference on Music Perception and Cognition, Kyoto, 1989), 383–88; see also John Sloboda, *The Musical Mind: The Cognitive Psychology of Music* (Oxford: Clarendon Press, 1985); see also Henry Shaffer, 'Performance of Chopin, Bach and Bartok: Studies in Motor Programming', *Cognitive Psychology*, 13 (1981), 326–76.

<sup>196</sup> Bruno Repp, 'Composers' Pulses: Science or Art', *Music Perception: An Interdisciplinary Journal*, 7.4 (1990), 424.

<sup>197</sup> His touch-sensitive input device was used to compose and perform musical gestures.

<sup>198</sup> Manfred Clynes, *Expressive Microstructure in Music, Linked to Living Qualities*, Studies of Music Performance (Stockholm: Royal Swedish Academy of Music, 1983), 6.

<sup>199</sup> Repp, *Ibid.*, 428+429.

<sup>200</sup> Clynes, *Ibid.*, 26.

specific pieces of music.<sup>201</sup>

- 1.9.22 Synthesizing performances using alternative senses: A visual approach has proven very powerful, given the limitation in natural human abilities to perceive patterns and trends in complex, tabulated numeric results. Bresin asked listeners to relate perceived expressivity in short performances to colours and sounds presented in real-time, with no prior information on possible colour-emotion relationships.<sup>202</sup> He proposed a mobile device to align conventional score notation to real-time music performance data including not alone colour, but shape, hue and size. His results show reasonably consistent mapping between colours and emotions, although he explains that the relationship is instrument-related.
- 1.9.23 Performance (dis)similarity: Researchers have measured vibrato depth by inspection of spectrographic visualizations. Research indicates that newer performances are ‘less idiosyncratic’ due to the ‘rise of the recording industry and the canonization of certain recordings made by authoritative figures’.<sup>203</sup> Univariate vectors can represent performances, although Euclidean Distances between pairs of such vectors were found to be unsatisfactory as a basis for clustering performances although may also be explained by the limited amount of data available.<sup>204</sup> An alternative measure, such as Mahalanobis Distance might have been a more appropriate alternative, had they used multivariate vectors, since it can deal with covariances between variables. Stamatatos used a computer-monitored piano to show that a performance average, when calculated on specific variables, may be a better discriminant between performances than attempts to relate performances to a printed score: using IOIs to calculate average IOI is acceptable but it is not clear how he calculated average dynamic levels.<sup>205</sup> Asmus reports that characteristic effects, ranking ‘in descending order as: tempo, mode, pitch, harmony, rhythm and melody’ have been used since the 1920s to measure listener

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<sup>201</sup> Dirk Moelants, ‘Preferred Tempo Reconsidered’, in *Proceedings of the 7th International Conference on Music Perception and Cognition*, ed. by C Stevens and others (presented at the 7th International Conference on Music Perception and Cognition, Adelaide: Causal Productions, 2002), 4.

<sup>202</sup> Roberto Bresin, ‘What Is the Color of That Music Performance?’ (presented at the International Computer Music Conference, International Computer Music Association: Barcelona, 2005), 2.

<sup>203</sup> Elad Liebman, Eitan Ornoy and Benny Chor, ‘A Phylogenetic Approach to Music Performance Analysis’, *Journal of New Music Research*, 41.2 (2012), 196.

<sup>204</sup> Liebman, *et al.*, *Ibid.*, 214.

<sup>205</sup> Efsthathios Stamatatos, ‘Quantifying the Differences between Music Performers: Score vs. Norm’, in *Proceedings of the International Computer Music Conference (ICMC’2002)* (Göteborg: ICMC, 2002), 1.

response to expressive performances.<sup>206</sup>

1.9.24 Generative approaches to automated performances: These are based, like Chomsky's generative theories of language, on sets of rules that are organized into hierarchies.<sup>207</sup> These hierarchies form complete *performance grammars* that determine how performances may be generated from scores. A performance average based on linear average of IOIs and MIDI velocities produces a performance that is musically quite acceptable, in respect of timing, to musically trained listeners.<sup>208</sup> Such theories have succeeded in explaining expressivity in the auditory sphere, ignoring physical movement and participant cross-communications. One application of such generative theories is to construct computerized performances from scores.<sup>209</sup> A further development of that approach is a class of *transformational rules* that can manipulate a complete rule hierarchy to generate preferred ways of performing music. Lehrdahl and Jackendorff define musical structure as a 'mental product' in their study of the generative theory of tonal music. The ability of an acculturated listener to organize sounds into meaningful structures is determined by familiarity with the idiom, not so much with formal musical education. According to Timmers and Honing, this may be similar to how performers might agree on structures yet maintain 'different strategies to express the interpretation'.<sup>210</sup> One use of the generative approach has been in modeling performances to derive parameters, rules and grammars all of which can subsequently be fed back into computerized performances.<sup>211</sup> Rule analysis was extended further with the GERM model by techniques to incorporate rules for random variability and 'stylistic unexpectedness'.<sup>212</sup> GERM is fully implemented in the *Director Musices* software

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<sup>206</sup> Edward Asmus, 'The Measurement of Musical Expression' (presented at the Suncoast Music Education Research Symposium, Tampa, Florida, 2009), 2.

<sup>207</sup> Chomsky, Noam, *Aspects of the theory of syntax*, (Cambridge MA: MIT Press, 1965), §1, 5.

<sup>208</sup> Patrick Juslin, 'Can Results from Studies of Perceived Expression in Music Performances Be Generalized across Response Formats?', *Psychomusicology*, 16 (1997), 77–101; see also Edward Asmus, 'The Measurement of Musical Expression', Suncoast Music Education Research Symposium, Tampa (2009), and Bruno Repp, 'The Aesthetic Quality of a Quantitatively Average Music Performance: Two Preliminary Experiments', *Music Perception*, 14.4 (1997), 419–44.

<sup>209</sup> Fred Lehrdahl and Ray Jackendorff, *A Generative Theory of Tonal Music* (MA: MIT Press, 1983), 5+11.

<sup>210</sup> Lehrdahl and Jackendorff, *Ibid.*, 2. See also Timmers and Honing, *Ibid.*, 26.

<sup>211</sup> Alfonso Perez and others, 'Expressive Irish Fiddle Performance Model Informed with Bowing', in *Proceedings of ICMC* (presented at the International Computer Music Conference, ICMA/Michigan Publishing, 2008), <http://hdl.handle.net/2027/spo.bbp2372.2008.115>.

<sup>212</sup> Each letter in GERM represents an expressive performance feature – G is *generative rules*, E is *emotional expression*, R is *random variations*, M is *motion principles*. see Patrick Juslin, Anders Friberg and Bresin, 'Towards a Computational Model of Expression in Music Performance: The GERM Model', *Musicae Scientiae*, 2002, 66.



program.<sup>213</sup> A team, at KTH Royal Institute of Technology, Stockholm developed one of the first theoretical, rule-based systems for computer performance from scores. Rules in their system model phrasing, articulation and intonation. They also control tone, inter-onset duration, loudness and pitch. The system was developed over two parallel routes – *analysis by synthesis* (implementing rules from a model and then refining them) and *analysis by measurement* (using performance data to extract rules).<sup>214</sup> The system's rules use local context to predict variables and model the emotional impact of performances. In a follow-on study, Friberg and colleagues applied the rules to atonal music of Boulez and Xenakis, finding that their approach does

appear to serve the purpose of helping the listener in identifying the structural elements in terms of duration and pitch categories. The grouping rules facilitate the grouping of notes into phrases. The results suggest that the listener appreciates help in these tasks when listening to contemporary atonal music.<sup>215</sup>

- 1.9.25 Style and shaping: The uniformity of musical sound that is now ubiquitously available was not what listeners could have perceived in any era before smartphones, MP3 players, or portable computers. Understanding music is like understanding patterns in words and sentences: the process is not just a fundamental task of analyzing what letters are in the sentence; rather, it is a process of grouping events and processes that may sound subtly different on each hearing. It is probable that the emotional state of the listener and even background sounds in a concert hall contribute to differences. This involves parsing low-level sounds into higher-level elements; just as spoken words in any language have a rhythm and cadence that help impart meaning. Familiarity helps enormously since humans' music parsing processes operate on continuous streams of information that must be identified, organized and structured. Within the conventional tonal music tradition there are signposts along the way, both composing and performing conventions. For twelve-tone music, the stream of sonic events, which may in any case be inadequately, or ambiguously, signalled by a performer, poses difficulties for

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<sup>213</sup> See download page at <http://www.speech.kth.se/music/performance/download/dm-download.html>. Accessed: July 1, 2014. See also Patrick Juslin, 'Studies of Musical Performance: A Theoretical Analysis of Empirical Findings', in *Proceedings of the Stockholm Music Acoustics Conference*, ed. by Roberto Bresin (Stockholm: Department of Speech, Music and Hearing, Royal Institute of Technology, 2003), §II, 513–16.

<sup>214</sup> Anders Friberg, Roberto Bresin and Johan Sundberg, 'Overview of the KTH Rule System for Musical Performance', *Advances in Cognitive Psychology*, 2.2-3 (2006), 146.

<sup>215</sup> Friberg *et al.*, *Ibid.*, 54.

comprehension.

1.9.26 Form and structure: Quite how a performer's overall structural considerations are imposed on the musical variables is a major issue, although Williamon *et al.* note that structural segmentation analyzed in rehearsal can be a significant memory aid during performance, even more so for professional musicians.<sup>216</sup> In 1928, Cortot performed the finale to Chopin's Piano Sonata No. 2 in B-flat minor with sparse pedal or dynamic contrast. Barolsky explains Cortot's interpretation as an 'unremitting rhythmic drive', backed up by one crescendo, an interpretation that may be justified by Chopin's sole dynamic marking in the final bar.<sup>217</sup> By way of explanation, Barolsky offers the proposition that analysis may include the development of systematic cues that hide, or highlight, features.<sup>218</sup> Performers of modernist music may introduce 'expressive' shaping where none is actually indicated by the composer. Barolsky argues that music from the 1970s to 1990s, which he views as over-notated, sounds very much like it looks.<sup>219</sup> For Heaton, notational forms can lead performers to a 'better understanding of style'. Instrumental style and composition are inevitably intertwined. Innovations in compositional techniques require musicians to innovate performance techniques. This process leads to reciprocal changes by composers.<sup>220</sup> It is not just in respect of musical performance style that change can be perceived. Heaton remarks on changes that followed WWII such as the 'demise of the string quartet as the standard-bearer of all that is new and experimental' and the participation, in small groups, of expert soloists that were never trained to be orchestral musicians.

1.9.27 Performer as analyst: An important aspect of performance is how a performer, having conceived structural aspects of a work, forms a mental hierarchy and communicates information about those structures during performance.<sup>221</sup> Perhaps this does not warrant that a specific performer's structural viewpoint coincides with the composer's intent. In

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<sup>216</sup> Aaron Williamon, Elizabeth Valentine and John Valentine, 'Shifting the Focus of Attention between Levels of Musical Structure', *European Journal of Cognitive Psychology*, 14.4 (2002), 493–520 (p. 497).

<sup>217</sup> Barolsky, *Ibid.*, §8.

<sup>218</sup> Barolsky, *Ibid.*, §27.

<sup>219</sup> Roger Heaton, 'Contemporary Performance Practice and Tradition', *Music MPS research*, 5 (2012), 97).

<sup>220</sup> Heaton, *Ibid.*, 99.

<sup>221</sup> Jennifer MacRitchie, 'Elucidating Musical Structure through Empirical Measurement of Performance Variables' (PhD dissertation, University of Glasgow, 2011), 15. <http://theses.gla.ac.uk/2357/>. Accessed: 23 January 2017.

twelve-tone music, analytical difficulties may be more acute than in earlier styles. At an early stage in preparing a musical work for performance, a skilled performer must decide on how to frame an individual interpretation considering form, structures, phrasing and segmentation. Several scholars support this view of the performer as analyst, notably Barolsky.<sup>222</sup> Palmer points to three sources of evidence for the influence of musical structure on expressivity, as in how expressive delivery in performance is to some extent conditioned by structure: (a) constancy of individual performers' expressive timing profiles over long periods, (b) ability to modify expression without practice and (c) ability to apply appropriate expression while sight-reading. There is a consequence to the view that structure generates expression: it would imply there is a difficulty in repeating performances of music that 'contains an arbitrary relationship between expression and structure'.<sup>223</sup>

1.9.28 Information and Communications theory: Musicological research has attempted to relate Shannon's formal theory of information to music.<sup>224</sup> The foundation of his theory is that all information transfers, whether between devices or people, may be encoded such that a decoding system can reliably determine the original information. The degree of random noise in the transfer is termed *entropy* and a reliable decoding system should be able to determine the information even in the presence of noise. The degree of predictability in any part of a message is in inverse proportion to its value. In terms of music performance, the performer is a message source and the listener a message receiver. For example, in typical tonal music, the final cadence of any major key work will often be a V-I progression. Even without the final tonic chord, a listener can anticipate it. The amount of information content in the actual delivery of the final chord, under Shannon's theory, is redundant. Entropy is the degree of randomness, or unpredictability, in a system. As mentioned previously, Leonard Meyer's contribution to the relevance of information theory for music was to relate the concept of *expectancy* to Shannon's theory of information.<sup>225</sup> This raised an important issue, addressed by Culpepper, for post-tonal and unfamiliar musics where high entropy 'indicates [a] very

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<sup>222</sup> Daniel Barolsky, 'The Performer as Analyst', *Music Theory Online*, 13.1 (2007), §2.

<sup>223</sup> Palmer, *Ibid.*, 126. This is a reference to Henderson, Seashore, Shaffer and Sloboda.

<sup>224</sup> Claude Shannon, 'A Mathematical Theory of Communication', *Bell Systems Technical Journal*, 27 (1948), 623–56.

<sup>225</sup> David Huron and Elizabeth Margulis, 'Music Expectancy and Thrills', in *Handbook of Music and Emotion: Theory, Research, Applications*, ed. by Patrick Juslin and John Sloboda (Oxford: Oxford University Press, 2010), §21 ¶21.7.1.

little repetition, which implies a fair amount of discontinuity'. Working in this medium, a composer must make great efforts to establish attainable musical goals and listeners must work hard to understand the message.<sup>226</sup> This may explain a trend that will be demonstrated in performances of the *Phantasy*. Performers may be simplifying the message in order to communicate it more effectively. Cohen made a reasoned argument for an information theory of music.<sup>227</sup> He believed that many aesthetic arguments fail because the reader does not know what the author is trying to say. Virtually no message is being communicated. He points out the importance of Leonard Meyer's earlier work on emotion and style: beginning with the concepts of expectation and affective response and working towards formal statistical and probabilistic analysis of musical style.<sup>228</sup> He also notes the importance of understanding that the brain receives a musical message by comparing successive events rather than a totality of absolute values. The contents of such a conceptual message cover perhaps more variables than can be conceived. It may be the case that the marginal information from manipulating more distant variables adds little incremental value to the musical communication. Using Eitan's metaphor, some set of salient variables form the *intensity contours* of a music performance as it moves forward in time. One challenge to MPS research is to find a way to represent those intensity contours in such a manner as can be examined analytically. There is also the issue of physical performer error, whether a specific expressive gesture was actually intentional, or due to random error. This is perhaps of less importance in respect of the historic canon of tonal scores—the twentieth century has seen compositions of vast complexity, some of which have been reckoned as unplayable when first published.<sup>229</sup> However difficult any work may appear at first reading, musicians have shown an extraordinary ability to evolve specialist skills to deal with such challenges. Rumson believes that Nancarrow's *Sonatina* is unplayable.<sup>230</sup> Stravinsky's *Rite of Spring* calls for triple-stop violin chords that his contemporaries Dushkin and Heifetz both deemed unplayable.<sup>231</sup> Yet modern professional orchestras have this work within their standard

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<sup>226</sup> Sarah Culpepper, 'Musical Time and Information Theory Entropy' (Master of Arts, University of Iowa, 2010), 74.

<sup>227</sup> Joel Cohen, 'Information Theory and Music', *Behavioral Science*, 7.2 (1962), 137–63.

<sup>228</sup> Leonard Meyer, *Emotion and Meaning in Music* (Chicago: University of Chicago Press, 1956).

<sup>229</sup> Dirk Moelants, 'Statistical Analysis of Written and Performed Music. A Study of Compositional Principles and Problems of Coordination and Expression in "Punctual" Serial Music', *Journal of New Music Research*, 29.1 (2000), 44.

<sup>230</sup> Gordon Rumson, 'Conlon Nancarrow', in *Music of the Twentieth Century Avant-Garde: A Biocritical Sourcebook* (Westport, CT.: Greenwood Press, 2002), 321.

<sup>231</sup> Robert Craft, CD liner notes to Igor Stravinsky, 125th Anniversary Album - The Rite of Spring / Violin Concerto (Naxos 8.557508, 1967).

repertoire. Moelants makes a similar point in relation to the important Belgian composer Karel Goeyvaerts's *Sonata No.1* for two pianos (see extract in Fig. 1.1). It is an *Integral Serial* work with no indicated phrasing or structure (much to Adorno's surprise on encountering that work on a Darmstadt visit).<sup>232</sup> Goeyvaerts serializes numerical values of pitch, duration, loudness and mode of attack such that their sum is nearly always the numeric value seven, a performance target that is clearly difficult to achieve accurately, if at all.<sup>233</sup> Moelants attempts to measure the extent to which performers can eliminate expression completely, since Goeyvaerts's metaphysical compositional approach dictates that his notated pitches always contain the totality of information required to perform them. Even highly experienced performers find this almost impossible to achieve in the absence of consistent dynamics or articulation. Proper performance of *Sonata No.1* requires the work to be performed without any added interpretation, exactly as written even though onset events are spaced so widely as to counter the development of any overall sense of pulse or *tactus*. Moelants demonstrated that, while professional musicians may maintain a rhythm, the piece poses almost 'insuperable' performance difficulties at a micro level.<sup>234</sup> The performers were not being unfaithful to his score: they were incapable of executing it at the specified level of accuracy. Given that earliest attempts to perform Stravinsky's *Rite of Spring* originally suffered the same complaints, one wonders whether future performers might yet master Goeyvaerts's work, if indeed there is any long-term interest in performing it. Moelants tested if theoretical performance rules of contemporary keyboard music could be found empirically in performances. He found only scant evidence for two: (1) lengthening of short IOIs (deceleration at higher tempi), and (2) double duration (shortening the first note and lengthening the second in sequences of IOIs that have 2:1 ratio).<sup>235</sup> It is possible to conclude, therefore, that certain types of music do not facilitate normal modes of expressivity. Any changes in intensity levels are pre-ordained by the

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<sup>232</sup> Moelants, 'Statistical Analysis of Written and Performed Music. A Study of Compositional Principles and Problems of Coordination and Expression in "Punctual" Serial Music', p. 50. See also Martin Iddon, *New Music at Darmstadt: Nono, Stockhausen, Cage and Boulez* (Cambridge: Cambridge University Press, 2013), p. 55, 58. For a discussion of Integral (Total) Serialism, see Arnold Whittall, *The Cambridge Introduction to Serialism*, Cambridge Introductions to Music (New York, 2008), 273.

<sup>233</sup> Herman Sabbe, 'Goeyvaerts and the Beginnings of "Punctual" Serialism and Electronic Music.', *Revue Belge de Musicologie*, 48 (1994), 55+71. See also Iddon, *Ibid.*, 54.

<sup>234</sup> Moelants, *Ibid.*, 56-58.

<sup>235</sup> Anders Friberg and others, 'Performance Rules for Computer-Controlled Contemporary Keyboard Music', *Computer Music Journal*, 15.2 (1991), 50.

composer and leave very little scope for variation in performance.

Ex. 1.1 from 2<sup>nd</sup> Movement, Sonata No. 1 for 2 pianos, Karel Goeyvaerts<sup>236</sup>

1.9.29 Listener response: Daynes demonstrated how the valence of responses to atonal music was typically lower than to familiar tonal music, the lowest level responses coming from non-music students.<sup>237</sup> It must be admitted that the many confusing and conflicting views on the emotional components of music do not make it easy to generalize. It is certainly more difficult to reach consensus as to how intensity works when the impact on individual listeners may vary so considerably. Listeners to post-tonal music judge typical expressive gestures differently, since intensity changes at phrase-ends or cadences, that might otherwise make sense in the context of tonal music, may not be

<sup>236</sup> Iddon, *Ibid.*, 56.

<sup>237</sup> Helen Daynes, 'Listeners' Perceptual and Emotional Responses to Tonal and Atonal Music', *Psychology of Music*, 39.4 (2010), 468. See also Patrick Juslin and Daniel Västfjäll, 'Emotional Responses to Music: The Need to Consider Underlying Mechanisms', *Behavioral and Brain Sciences*, 31 (2008), 559. Also see *Music and Emotion: Theory and Research*, ed. by Patrick Juslin and John Sloboda, Series in Affective Science, 1st edn, 2001. See also Tia DeNora, *Music in Everyday Life* (Cambridge: Cambridge University Press, 2000), 65.

appropriate to the newer paradigm. Unless a work, or at least its musical type, is familiar to a listener, they hear sounds that are probably at or beyond the boundaries of their experience, or any pre-formulated context. Coming to such music fresh means that expectations of what is unfolding may not refer to a listener's experience, in a way that ears accustomed to standard conventions of tonality may have an expectation of structures in an unfamiliar piece of music. Musical expectation is a complex psychological phenomenon that involves two separate phases: the pre-outcome (*imagination*) and the post-outcome (*response*).<sup>238</sup> Margulis investigates whether eventual emotional response to *affective* content may be predicted from a study of the score.<sup>239</sup> She assigns ratings to degrees of tension that are likely to be implied by the music. This approach does have an advantage of not requiring listeners to have a mental picture of structures in advance of performance, yet it assumes they possess well-developed musical literacy both in terms of forms and of performance conventions. Repeated listening develops a different sense of what is expected. According to Huron, Meyer termed this the 'choreographing of expectation'.<sup>240</sup> Score notation of western art music indicates what is to be delivered but provides, at best, a very minimal indication of how music should sound. In one respect, the notion of a score demands conformance whereas the nature of great performances is to deviate from the standard. Both Popper and Ingarden conceived of a musical work's existence being as 'that of a unicorn': even where modified, it is still an intentional object without real existence.<sup>241</sup> Music is neither just a score, nor just a performance, nor even all performances combined. Narmour's conception of music is close to Ingarden's concept of an *intentional object* when he states that it is the 'fusion of ... composer, performer, listener—that literally creates the musical artwork out of thin air'.<sup>242</sup> MPS presumes that each instantiation will be

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<sup>238</sup> David Huron, *Sweet Anticipation: Music and the Psychology of Expectation* (MA: MIT Press, 2006), 7–8.

<sup>239</sup> Elizabeth Margulis, 'A Model of Melodic Expectation', *Music Perception*, 22.4 (2005), 663–714. *Affekt*, the 'doctrine of affections', is a term used to describe the emotion of a movement, passage, or work; and 'There the composer has the grand opportunity to give free rein to his invention. With many surprises and with as much grace he there can, most naturally and diversely, portray love, jealousy, hatred, gentleness, impatience, lust, indifference, fear, vengeance, fortitude, timidity, magnanimity, horror, dignity, baseness, splendour, indigence, pride, humility, joy, laughter, weeping, mirth, pain, happiness, despair, storm, tranquillity, even heaven and earth, sea and hell, together with all the actions in which men participate' from Johann Matheson, *Neu-Eröffnete Orchester* (1713), trans. by BC Cannon (Yale: Yale University Press, 1947), 129.

<sup>240</sup> Referred to in David Huron, *Ibid.*, 2.

<sup>241</sup> Leo Treitler, 'History and the Ontology of the Musical Work', *The Journal of Aesthetics and Art Criticism*, 51.3 (1993), 483.

<sup>242</sup> Eugene Narmour, 'On the Relationship of Analytical Theory to Performance and Interpretation', in *Explorations in Music, the Arts and Ideas: Essays in Honor of Leonard B. Meyer* (NY: Pendragon Press, 1988), 318.

different yet possessing performer-related characteristics in common.

### 1.10 Performing style

As was noted at §1.8 above, it would seem reasonable to propose that a music performing style could change over time, whether for socio-cultural, technical or other reasons. There is a countervailing possibility that a work, or class of works, might be so unique that no consistent performance style could stabilize and that each performance could exhibit such random characteristics as to consign it to stand permanently separated from all other performances. The fifty years prior to the *Phantasy*'s composition witnessed significant examples of performing style changes, for example: the virtual elimination of portamento in vocal performances, more consistent use of vibrato and tremolo, and generally more secure pitch with tighter adherence to tempo in ensemble playing. Orchestral recordings, particularly, of the early twentieth century often exhibit poor coordination and wild tempi: Worthington points to notable improvements in the standard of orchestral playing, particularly in London, during the early part of the twentieth century from 'messy or undisciplined playing' towards an 'increasing tightness of ensemble and rhythmic discipline [...] along with an improvement in the intonation and blending of woodwind sections'.<sup>243</sup> She also concludes that Elgar and Stravinsky both valued somewhat 'loose standards of playing', suggesting that an element of 'dash' was characteristic of orchestral performance style of the inter-war period.<sup>244</sup> As to opera singers, Potter shows that, by the 1930s, *portamento* was considered a poor performance technique unless marked specifically on a score, although his analysis shows that several current opera singers from the Eastern European tradition, such as Angela Gheorghiu, continue to retain a portamento style.<sup>245</sup>

String portamento also declined, as a favoured element of performing style, by mid-century but saw limited resurgence in performances by some important violinists born in the 1970s (Vengerov, Shaham, Barton).<sup>246</sup> Otherwise, Fabian and Ornoy do not

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<sup>243</sup> Worthington, Emily, 'The Modernisation of Wind Playing in London Orchestras, 1909-1939: A Study of Playing Style in Early Orchestral Recordings.' (PhD Dissertation, University of York, 2013), 39.

<sup>244</sup> Worthington, *Ibid.*, 46.

<sup>245</sup> John Potter, 'Beggars at the Door: The Rise and Fall of Portamento in Singing', *Music and Letters*, 87 (2006), 543-4.

<sup>246</sup> Daniel Leech-Wilkinson, *The Changing Sound of Music: Approaches to Studying Recorded Musical Performances*, 1.1 edn (London: CHARM, 2010), §5, <http://www.charm.rhul.ac.uk/studies/chapters/intro.html>, Accessed: 15 January 2015.



discern major trends across time periods in performances of Bach's solo works, the Sonatas and Partitas, other than individual differences in aspects of violin playing.<sup>247</sup>

Developing a musical performance has been characterized as a trajectory of spiral decision-taking, moving from deliberate performance decisions to a more intuitive approach then back to more subtle decisions.<sup>248</sup> Great musicians may not require, or may short-circuit such an approach: Menuhin states clearly in a television interview with Glenn Gould that he does not understand Schoenberg's music and instead relies on Gould to lead the way, for both of them, in interpreting it.<sup>249</sup> On the one hand, this appears to imply that Menuhin easily transported his technique and experiences to the unfamiliar medium of expression. On the other, it may imply that his technique was sufficient in any case to make any performance of any music stand out. Supposedly memorising the *Phantasy* overnight, something for which Gould was equally renowned, Menuhin performed it with undoubted facility.<sup>250</sup> There is equally the likelihood that multiple threads of performance style may persist contemporaneously. Mattes points to two recordings of the *Phantasy*: one from 1951 by Rudolf Kolisch and one from 1953 by Tibor Varga as examples. Varga 'epitomized what Kolisch opposed, that is, the romantic virtuoso's straightforward display of *beautiful tone*'. His performance sounds 'ascetic and at the same time full of frantic activity'.<sup>251</sup>

Evolution in performing styles over the period from 1950 onwards was perhaps conditioned in part by the ubiquity of recordings from a wide variety of interpreters, some of who received their formative musical education at the end of the nineteenth century. According to Katz, it is possible to hear differences between the way musicians perform live as opposed to their studio recordings.<sup>252</sup> Key surface artefacts, such as tempo and dynamics, which are likely influenced by hearing other performers play, are not themselves the only differentiators of performance sound. Differentiators may be

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<sup>247</sup> Fabian and Ornoy, *Ibid.*, 38.

<sup>248</sup> Daniel Bangert, Emery Schubert and Dorottya Fabian, 'A Spiral Model of Musical Decision-Making', ed. by Aaron Williamson, *Frontiers in Psychology*, 5.330 (2014), 6, <http://dx.doi.org/10.3389/fpsyg.2014.00320>.

<sup>249</sup> Canadian Broadcasting Corporation, *Menuhin and Gould in Conversation about Schoenberg* <https://www.youtube.com/watch?v=av2XTNgA72w>, Accessed: 13 June 2013.

<sup>250</sup> Otto Friedrich, *Glenn Gould: A Life and Variations*, Reprint. (NY: Random House, 1990), 17-18.

<sup>251</sup> Arnulf Mattes, 'Performance as Critique', in *Transformations of Musical Modernism*, ed. by Erling Gulbrandsen and Julian Johnson (Cambridge: Cambridge University Press, 2015), 252.

<sup>252</sup> Mark Katz, 'Capturing Sound: How Technology Has Changed Music', *Washington Post* (Washington, 26 July 2005), <http://www.washingtonpost.com/wp-dyn/content/discussion/2005/07/21/DI2005072101733.html>, Accessed: 26 January 2016.

sought in some more profound aspects of performance that mix individualistic components with influences from other performers.

### 1.11 Pedagogy

In order to provide useful feedback to a performer tackling a complex piece for the first time, an analysis provides detailed information as to form and content. A separate goal is to be able to select from alternative ways of performing the piece and thereby enhance a listener's experience.<sup>253</sup> The latter ideal requires something different both from textual analysis and from examination of socio-historical context, accepting that there may be no single best way of achieving it. Friberg and Battel proposed that analysis can benefit from computational approaches: (1) pedagogical benefits – phrasing, shaping and articulation may be explained to students on the basis of how expert musicians vary tempo and dynamics, and (2) auditory benefits - software, such as *Director Musices*, may be used to develop students' auditory skills by helping to distinguish between different treatments.<sup>254</sup>

A performance needs to assume aspects of musical form and structure in order to prioritize musical events and establish expressive intensity within a performance. It may be the case that the more skilled a performer is in analytical techniques, the better informed are his/her performances. This appears to imply a *referentialist* (i.e. language-like) view of music rather than a sound-driving-emotion view, such that risk-taking and innovation combine to deliver impact.<sup>255</sup> In a *referentialist* approach there is the assumption that better communication leads on from higher language skills, ignoring the importance of expressive intent. In using MPS to drive pedagogical developments there is a danger of over-focussing on copying the actual implementations of experienced performers, rather than understanding a variety of styles. An analytical approach that suits one work, or one composer, may not work for others. That does not negate the importance of undertaking a performance analysis as a basis for understanding other than what can be learned intuitively. It has been reported that 'analysing and labelling music gives the performer a more effective means of

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<sup>253</sup> Janet Schmalfeldt, 'On the Relation of Analysis to Performance: Beethoven's "Bagatelles" Op. 126, Nos. 2 and 5', *Journal of Music Theory*, 29.1 (1985), 1.

<sup>254</sup> Friberg and Battel, *Ibid.*, 209.

<sup>255</sup> Stephen Brown, 'The "Musilanguage" Model of Music Evolution', in *The Origins of Music*, ed. by Nils Wallin, Björn Merker and Stephen Brown (Boston: MIT Press, 2000), 271.

discovering relationships within the material, thus committing to and solidifying it'. Theoretical understanding can also assist memorisation by improving the ability meaningfully to 'chunk' a work of music.<sup>256</sup>

Perhaps it is not objectively bad that less skilled performers should emulate more masterful performers. In many fields, copying the work of masters is seen as an appropriate way to learn technique. Conservatories in Scandinavia have adopted just such an emulation approach to training musicians, using what they term an *apprenticeship model* to promote *learning by imitation and by performance*.<sup>257</sup> The apprentice learns by copying a master's performances and from other apprentices in a community of practice. Nielsen points out that Scandinavian languages translate this as 'master learning' (*maesterlaerle*) and that the learning philosophy is based on imitation as 'a part of a dialogue between the reflective practitioner and his student'.<sup>258</sup>

By the turn of the twenty-first century it had become difficult to find entrants to top-flight music competitions that did not already exhibit virtuosic technique, even if they lacked such fully rounded musicality that may come with experience.<sup>259</sup> This underscores the importance of a reflective approach.

## 1.12 How to measure and analyze performances

The underlying motivation of the present research is to develop a model that can deliver results, be replicated on different musical data and extended. The techniques that are applied herein may be extended to encompass a wide range of performance variables, without materially altering the overall model approach. It is important to assemble techniques that can collect music performance data at any level of definition.

This dissertation is not intended as a statistical or mathematical analysis. It brings tools and techniques from other disciplines into musicology in an attempt to augment the

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<sup>256</sup> 'Chunking' is a term used by several researchers to mean the identification of musical subsets for memorisation purposes. See Edward Large, Caroline Palmer and Jordan Pollack, 'Reduced Memory Representations for Music', *Cognitive Science*, 19 (1995), 56–57; see also Mark Egge, 'Toward a Method for Performance Analysis of Twentieth Century Music' (Masters dissertation, 2005), 5; and see also Elias Pampalk, 'Computational Models of Music Similarity and Their Application in Music Information Retrieval' (Doctor of Technical Sciences dissertation, 2006), 16.

<sup>257</sup> Klaus Nielsen, 'Apprenticeship at the Academy of Music', ed. by Tom Barone and Liora Bresler, *International Journal of Education and the Arts*, 7.4 (2006), 1.

<sup>258</sup> Nielsen, *Ibid.*, 7.

<sup>259</sup> Christopher Small, *Music, Society, Education* (Hanover & London: Wesleyan University Press, 1996), 193.

debate around expressivity and performance style without being concerned with the cognitive or mechanical processes that enable listeners to track variables, or even the higher-order processes that conceive of structures.<sup>260</sup> A very different emphasis is maintained in studies of how alterations to harmonies and voice leading can influence how listeners receive performances.<sup>261</sup> This is critical in respect of twelve-tone music: Raffman argues that the gap between a twelve-tone composition and human cognition is so wide as to be realistically unbridgeable by ordinary audiences.<sup>262</sup> Her argument appears to be that it is impossible to overcome all possible difficulties in comprehending what is going on in such music.

MPS research has been particularly aided by the increased availability and sophistication of computers and analytical tools. In the bulk of published papers, books and dissertations, researchers have used music from the western art music canon. Yet, we are still very far from truly understanding the ‘aesthetic aspects of music performance and experience’: the subtlest aspects of tone and performance have not yet been satisfactorily explained in terms of physical variables.<sup>263</sup> Simple correlations are not sufficient explanations of real musical relationships: *correlation* must never be conflated with *causation*.<sup>264</sup>

It is important to distinguish between performance-wide acceleration/deceleration and *rubato*. The *rubato* effect is invariably used as a localized expressive device which in Todd’s terms is the common ‘phrase final lengthening’ that signals a musical boundary.<sup>265</sup> Timmers and colleagues support this view while also emphasising that melody is of primary importance in the tempo structuring process.<sup>266</sup> In Steurman’s recording of Schoenberg’s Piano Piece Op. 11, No. 2, he achieves non-notated, agogic accents by lagging certain notes that are notated in the score as being simultaneous.<sup>267</sup> For the present research, acceleration/deceleration refers to micro-timing changes at a

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<sup>260</sup> Eric Clarke, ‘Mind the Gap: Formal Structures and Psychological Processes in Music’, *Contemporary Music Review*, 1989, 3.1, 2.

<sup>261</sup> Richard Parncutt, ‘Applying Music Psychology to Music Education: Can Perceptual Theory Inform Undergraduate Harmony?’ (presented at the International Music Education Research Symposium, Launceston, Tasmania, 1999), 254.

<sup>262</sup> Diana Raffman, *Ibid.*, 72.

<sup>263</sup> Gabrielsson, *Ibid.*, 258.

<sup>264</sup> Gabrielsson, *Ibid.*, 227–8.

<sup>265</sup> Neil Todd, ‘A Computational Model of Rubato’, *Contemporary Music Review*, 3 (1989), 69.

<sup>266</sup> Renee Timmers and others, ‘The Influence of Musical Context on Tempo Rubato’, *Journal of New Music Research*, 29 (2000), 131+132.

<sup>267</sup> Cramer. *Ibid.*, §1.

beat level, continuously throughout the work. Some proportion of these timing variations is likely due to variation in motor-level processes that are outside any player's control. Some may be due to researcher measurement errors, or to random errors caused by random noise in the input signals.

Krumhansl proposed that listeners unconsciously apply Gestalt-like principles, naturally grouping musical features to boost comprehension of the entire musical work.<sup>268</sup> A listener may be likely to disengage when there is neither an imagined event, nor a satisfactory response. The likelihood is predictably slight that surprise alone is sufficient to develop an understanding.<sup>269</sup> Musically informed and curious listeners will generally have a better chance of categorising and structuring unfamiliar music, whatever the genre.<sup>270</sup> For the less musically literate, it may be that melody or rhythm alone, rather than formal structures, are the most significant discriminants of what is enjoyable and what is not.

### 1.13 Other modifications

Expressive performance may involve actions other than just modification of tempo or dynamics. Studies of Glenn Gould's playing find a strong correlation between physical movement and expressive characteristics of the music.<sup>271</sup> Caution is needed in respect of how humans assess such gestures and the physical attributes of performance. Thompson and Williamon note video experiments in which the audio of both black and white performers was identical. The black performances rank significantly lower in quality although differences due to gender did not affect the rankings.<sup>272</sup> There appears to be racial bias involved in the latter assessments since the audio track was consistently identical.

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<sup>268</sup> Tendencies to group 'have been central to various psychological theories of musical structure' emphasizing the importance of 'the function of each tone in the perceptual whole—the melody'. Carol Krumhansl, *Cognitive Foundations of Musical Pitch*, Oxford Psychology Series 17 (New York: Oxford University Press, 1990), 282.

<sup>269</sup> Huron, *Ibid.*, 29.

<sup>270</sup> Paul Elvers and others, 'Exploring the Musical Taste of Expert Listeners: Musicology Students Reveal Tendency toward Omnivorous Taste', *Frontiers in Psychology*, 6: Article 1252, §Introduction.

<sup>271</sup> Marcelo Wanderley, 'Quantitative Analysis of Non-Obvious Performer Gestures' presented at the GW 2001 LNAI 2298, Berlin: Springer-Verlag, 2002), 242.

<sup>272</sup> Thompson and Williamon, *Ibid.*, 27.

### 1.14 Aesthetics and twelve-tone music

Twelve-tone music is a conjunction of events, pitches and sounds, that may offer small possibilities of appealing to listener feelings such as, among others, fulfilment, longing, sadness, introspection, mirth or happiness. Even by 1910, Schoenberg was ‘bidding a reluctant farewell’ to the nineteenth century—a farewell that remained incomplete in the sense that he continued to draw so much upon Wagner, Brahms, Mahler and even Beethoven and Bach.<sup>273</sup> Consider a letter from 1949 written by painter Kokoschka to Schoenberg, should there be any doubt of the impact of his music:

I wept as I listened to the Fourth Quartet. Now I know for certain that you are the last Classical composer. [... Bach, Beethoven and Schoenberg as the last composers capable of erecting a musical structure that can—must—be regarded as an organic world.<sup>274</sup>

Adorno positioned music as having a necessary social role. He defined two types of music: (1) ‘affirmative music’ that is understood to have a social role as a commodity, whether popular, historical art music (both of which he considered as products for market distribution) or modern music that makes compromises over accessibility, and (2) ‘radical *serious* music of the avant-garde’ that makes no such compromises to popularity or accessibility.<sup>275</sup>

He understood Schoenberg’s striving for a new, pure musical language, but doubted whether this could be achieved in music’s necessary engagement with society because, absent that engagement, music has no independent role. Boulez notes three important ways that Schoenberg developed his late style: ‘non-repetition, the preponderance of *anarchic intervals* ... and progressive elimination of the octave’.<sup>276</sup> Leech-Wilkinson remarks that changes in the aesthetic viewpoint of Boulez were due to his

responding to decades of performances and recordings and to a change in the general period aesthetic away from formalism and towards perception, a change which performances show just as well as and considerably before, academic analyses and commentaries.<sup>277</sup>

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<sup>273</sup> Cherlin, Michael, *Schoenberg’s Musical Imagination*, (Cambridge: Cambridge University Press, 2007), 21.

<sup>274</sup> Reported in Leon Botstein, ‘Music and the Critique of Culture: Arnold Schoenberg, Heinrich Schenker and the Emergence of Modernism in Fin de Siècle Vienna’, in *Constructive Dissonance: Arnold Schoenberg and the Transformations of Twentieth Century Culture*, ed. by Juliane Brand and Christopher Hailey (Berkeley: University of California Press, 1997), 3.

<sup>275</sup> Max Paddison, *Adorno’s Aesthetics of Music* (Cambridge: Cambridge University Press, 1993), 102.

<sup>276</sup> Boulez, *Ibid.*, 269.

<sup>277</sup> Daniel Leech-Wilkinson, ‘Musicology and Performance’, in *Music’s Intellectual History: Founders, Followers and Fads*, ed. by Zdravko Blazekovic and Barbara Mackenzie (New York: RILM, 2009), 798.

For Adorno, music contains within itself Marx's implied production-consumption imperative.<sup>278</sup> Its self-mediated distribution does not remove a requirement for understanding it. In other words, it remains critically important to Adorno's second category of music, including Schoenberg's twelve-tone works, that consumers (listeners) do not just hear sounds but make positive efforts to understand the language. Only by so doing can they confront the realities of their social existence with which all music is profoundly bound. Adorno specifically dismissed any worth in jazz just as Roger Scruton consistently decries popular music as 'lacking any harmonic movement of its own, it cannot move towards anything—certainly not towards anything that requires careful preparation, like a cadence'.<sup>279</sup> Gracyk interprets Adorno's philosophy as a belief that 'only twelve-tone music provides a dialectical resolution of the problems of Western music by its complete negation of prevailing conventions of production and convention'.<sup>280</sup> This view of composition assumes that a composer selects among possibilities to create a musical work. DuBiel urges 'as we continue to speak of Babbitt's music as twelve-tone, we try to undermine the received image of the twelve-tone system as a forceful method of construction and portray it instead as a loose and flexible way to define some possibilities of choice'.<sup>281</sup> The composer has an important role to fulfil: 'not to generate the meaning, but rather to cultivate in himself the skill for discerning the meanings that are already there' which of necessity implies 'intelligence and flexibility rather than rote and automatic response'.<sup>282</sup> Carl Dahlhaus, echoing Krumphansl (see §1.12) has shown that the transitory nature of music means the listener must attain a quasi-spatial *gestalt* of recall in order to bring it into existence as a 'closed whole'.<sup>283</sup> Schoenberg's serial system provides a *heuristic*, a way of suggesting possibilities, of 'finding ways to create, elaborate and solve problems'.<sup>284</sup> Boss relates the overall compositional processes of music, including Schoenberg's twelve-tone

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<sup>278</sup> Paddison, *Ibid.*, 145-147.

<sup>279</sup> Roger Scruton, 'Youth Culture's Lament: Pop Culture's Noise and Glamour Try in Vain to Fill a Gaping Void', *City Journal (Manhattan Institute)* (New York, Autumn 1998), Issue 42 edition <https://www.city-journal.org/html/youth-culture%E2%80%99s-lament-11849.html>, Accessed: 15 June 2016.

<sup>280</sup> Theodore Gracyk, 'Adorno, jazz and the Aesthetics of Popular Music', *The Musical Quarterly*, 76.4 (1992), 531.

<sup>281</sup> Joseph DuBiel, 'What's the Use of the twelve-Tone System?', *Perspectives of New Music*, 35.2 (1997), 37.

<sup>282</sup> Herbert Dreyfus and Sean Kelly, *All Things Shining* (New York: Simon and Schuster, 2011), 209.

<sup>283</sup> Carl Dahlhaus, *Aesthetics of Music*, trans. by William Austin (Cambridge: Cambridge University Press, 1982), 11-12.

<sup>284</sup> Arved Ashby, 'Schoenberg, Boulez and twelve-Tone Composition as "Ideal Type"', *Journal of the American Musicological Society*, 54.3 (2001), 586.

theory, to three concepts of rhetoric as taught in the eighteenth century: *Inventio* (the invention of ideas), *Dispositio* with *Elaboratio* (elaboration and variation) and *Elocutio* (working out and resolution).<sup>285</sup> The concept of taking a basic musical idea and developing it thoroughly looks forward to Schoenberg's *Grundgestalt*. There may be no evidence that Schoenberg read Hegel, but Boss suggests a possible second-hand, transferred, knowledge in that there are key parallels in both their aesthetics of art: (1) truth contains within itself a template for development, (2) development is a dialectical process of repeated cycles of opposition and synthesis, (3) the content and form of an artwork are not separable: any work of art fully represents its content.

Consider the way that audiences began to encounter twelve-tone music compared to the ways that modern art impacts upon its viewers. Alex Ross commented on the summons of a 2010 poster for a Jackson Pollock exhibition at New York's Museum of Modern art: 'Belong to something brilliant, electrifying, radical, curious, sharp, moving . . . unruly, visionary, dramatic, current, provocative, bold . . .'.<sup>286</sup> He also notes that over three hundred thousand visitors came to the Tate Modern to view an exhibition of Rothko's 'bleak', late canvasses. Few orchestras can attempt to promote any modern music in such positive terms nor to such numbers of people.

Daynes, like Raffman, has argued that listeners encounter significant difficulties in comprehending twelve-tone music, for example: not being able to rely on generic patterns or informed expectation.<sup>287</sup> He recommends that repeated listening can improve understanding. Whittall proposes that philosopher Roger Scruton does not see 'musical understanding as something dynamic and, like feeling, unstable' and that in reality a listener may never perceive the same work in the same way twice.<sup>288</sup> Since twelve-tone music seems to communicate better to people with musical training, several researchers have sought to explore which aspects of musical training are most important in developing understanding even if music may not always stimulate any specific or immediate emotion.<sup>289</sup> Even the rejection of Schoenberg's style in favour of more

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<sup>285</sup> Jack Boss, *Schoenberg's twelve-Tone Music: Symmetry and the Musical Idea* (Cambridge: Cambridge University Press, 2014), 10-11+12+16-17.

<sup>286</sup> Alex Ross, 'Why Do We Hate Modern Classical Music?', *The Guardian* (Manchester, 28 November 2010).

<sup>287</sup> Daynes, *Ibid.*, 13.

<sup>288</sup> Whittall, *Ibid.*, 20.

<sup>289</sup> Tia DeNora, *After Adorno: Rethinking Music Sociology* (Cambridge: Cambridge University Press, 2003); and see Patrick Juslin and others, 'An Experience Sampling Study of Emotional Reactions to Music: Listener, Music and Situation', *Emotion*, 8.5 (2008), 668-83.



extreme serialism by the immediate post-war generation of composers (including Boulez and Stockhausen) may be seen as a positive choice, coloured by their experiences of Nazism. Audience feelings must not be aroused basely by music in the way the European dictatorships abused the music of Beethoven, Wagner and others. Yet complex works, such as Boulez's 1955 composition *Le Marteau sans Maître*, which was well-received by musicians, composers and critics, faced poor listener reception mostly due to its impenetrable sounds and structures.<sup>290</sup> Barely five years later, Ligeti's *Atmosphères*, for example, evolved a significantly more beautiful sound on the basis of his own theories of serialism: dense clouds of clashing voices, and forward motion that evolves at an incredibly slow pace.

Taruskin, echoing Raffman and Daynes, believes that the goal of understanding twelve-tone music is essentially impossible being 'a conceptual game to which listeners can never gain perceptual access'.<sup>291</sup> Despite such views, and while Schoenberg's *Phantasy* may not be attractive to some, its dancelike character, its curious melodies and affective contrasts surely offer a wonderful listening experience.

### 1.15 Innovation and its evolution

It is reasonable to consider how music's semiotics, motifs and styles interact. Kolisch argued that music should not be a nationalistic marker, firmly rejecting the use of folk idioms. He anticipated Scruton's and Taruskin's view that music evolves on a base of tradition: 'especially twentieth century innovation'.<sup>292</sup> Stravinsky, took a different view, incorporating dirges and chorales in much of his music that specifically hark back to something archaic as a means of communicating with the past over a 'channel of mythical communication'.<sup>293</sup> Whittall questions Scruton's and Taruskin's 'evolutionary model' that dictates music must always be built on older foundations. Surely parallel, independent, radical innovations take place in music.<sup>294</sup> Can we remain unconscious of innovation and aware only of tradition? If so, then it is performers that must have the

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<sup>290</sup> Howard Goodall, *The Story of Music* (London: Random House, 2013), 310.

<sup>291</sup> Richard Taruskin, *Defining Russia Musically* (Princeton: Princeton University Press, 1997), 358.

<sup>292</sup> Rudolf Kolisch, 'Schoenberg as a Performing Artist', *Tempo, New Series*, 193 (1995), 34.

<sup>293</sup> Eero Tarasti, *Myth and Music: A Semiotic Approach to the Aesthetics of Myth in Music, Especially that of Wagner, Sibelius and Stravinsky* (The Hague: Mouton Publishers, 1979), 69.

<sup>294</sup> Arnold Whittall, 'Twentieth Century Music in Retrospect: Fulfilment or Betrayal?', *The Musical Times*, 140, (1999), 11.

foresight to engage in such discontinuities of technique and style as may lead to real style changes, both compositional and performing.

Schmuckler shows that investigation of contour formation and shaping across auditory variables was barely researched by the last decade of the twentieth-century, whether ‘explicit, continuous measures of similarity’ or features-based comparisons, or Schenkerian-like reduction of contours to maxima and minima.<sup>295</sup> McAdams’s large-scale study of continuous audience response was based on a performance of *Angel of Death* by Roger Reynolds.<sup>296</sup> This post-modernist composer believes that emotion derives not from the identification of thematic constructs but from their transformation, in performance, over time.<sup>297</sup> He ‘champions imputed breaks in knowledge, culture and society’ in the sense that post-modernism generally underscores scepticism towards the arts in general.<sup>298</sup> It proves extremely challenging for listeners to *Angel of Death* to perceive any structures whatsoever in this work. A short extract is shown in Extract 2.2, showing some of the composer’s detailed instructions to performers:

Ex. 2.2 Extract from *Angel of Death*, Theme 4.

<sup>295</sup> Mark Schmuckler, ‘Testing Models of Melodic Contour Similarity’, *Music Perception*, 16 (1999), 296–7.

<sup>296</sup> Roger Reynolds, *Angel of Death* (New York: C.F. Peters, 1998). See gallery of sketches, for first performance at IRCAM Paris, deposited at the Library of Congress at <https://www.loc.gov/resource/ihas.200029046.1?st=gallery>, Accessed: 20 November 2018.

<sup>297</sup> Stephen McAdams and others, ‘Influences of Large-Scale Form on Continuous Ratings in Response to a Contemporary Piece in a Live Concert Setting’, *Music Perception*, 22.2 (2004), 297–350.

<sup>298</sup> Stephen Best and Douglas Kellner, *Postmodern Theory: Critical Interrogations* (New York: Guilford, 1991), 29–30.

McAdams and colleagues noted how the setting itself (including factors such as quality of sound, seating arrangement and distance from sound source) contributes to emotional feeling. His research arose from discussions with Reynolds and a challenge to see if experimental psychologists could detect whether listeners experienced what a composer might intend.<sup>299</sup> Other researchers have built on this type of study, finding distinct motion styles at phrase boundaries by tracking performer movements on video.

Listeners come to surprisingly clear agreement on how to group phrases.<sup>300</sup> The initial work led towards phrase and structural shapes as natural data elements to be compared, rather than entire performances. And, importantly, it allowed the rate of change of tempo (rate of acceleration) to be used as a key variable in examining performance shaping. A multi-level approach to tempo modelling suggests that tempo is a composite of global, local and note-timing deviations that can be predicted using Bayesian techniques, although there is a fundamental problem in the lack of performance indicators on typical scores.<sup>301</sup> Dynamics are most strongly indicated by score notations, but local tempo and articulation are determined in performance. This dissertation demonstrates how the rate of increase/decrease in dynamics is not clearly bound to score notations and is a major determinant of uniqueness of performing style. The conventional symbols for crescendo and decrescendo, < and >, might be extended to show dynamic change over time by reference to notes, or bars. This seemingly precise, linear ascent/descent is probably not how a performer will approach dynamic change. Perhaps a better way to represent it might be to incorporate a dynamic curve into the symbols.

## 1.16 Chapter Summary

This chapter has shown that expressivity is not a random artefact that can arise from blind copying or repetition. It is a positive input by a musician, partially determined in advance of performance from analytical considerations and rehearsed actions, partially in real-time as the performance unfolds. Expressivity has been placed within a broad

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<sup>299</sup> Daniel Levitin (guest editor), 'Editorial: Introduction to the Angel of Death Project', ed. by Lola Cuddy, *Music Perception*, 22.2 (2004), 167.

<sup>300</sup> Sam Thompson, 'Determinants of Listeners' Enjoyment of a Performance', *Psychology of Music*, 35 (2007), 30; see also. MacRitchie, Buck and Bailey, *Ibid.*, 589-590.

<sup>301</sup> Sebastian Flossmann and Gerhard Widmer, 'Towards a Multilevel Model of Expressive Piano Performance', in *Proceedings of the International Symposium on MPS 2011*, ed. by Aaron Williamon, Darryl Edwards and Lee Bartel (presented at the International Symposium on MPS 2011, Utrecht: AEC, 2011), 642+646.

context of information communication. However, whether or not expressivity is used to communicate structural information is one hypothesis that will be explored in subsequent chapters.

The chapter considered the ontological position of musical works as art versus performance instantiations of them. It reviewed key scholarly researches in the empirical tradition, how performance styles have been modelled, the influence of aesthetics on music performance and the importance of expressivity and intensity.

It is usually problematic to generalize on the basis of limited samples. On the basis of the substantial number of quality recordings available to this research project, performances of the *Phantasy* will be shown to converge around a stylistic performance norm for selected variables. This may speak to reduced innovation, to reduced risk taking, or to an increased level of agreement as to what is the appropriate relationship between expression and shaping for such a piece of music. This will surely indicate a convergence of thought as to how to deliver appropriate expressivity, at least for this Schoenberg composition, and provide pointers to performance style.

## CHAPTER 2 | RECORDED MUSIC

There is a significant body of research into measuring performance variables and listener reception/perception from recordings.<sup>1</sup> This chapter highlights the salient characteristics of recording technologies and technical challenges that arise in using recordings as primary sources for research. Analytical research using recordings has typically delimited scope in line with what available tools and technologies could deliver. This has meant using musical extracts that concentrated on short, monophonic fragments, usually of tonal works that involve a single instrument. Different techniques were needed to adapt to the variety of sources, using analogue and digital formats including: piano rolls, wax cylinders, shellac and vinyl records, CD, DVD and MIDI.

### 2.1 Recordings versus live performances

Recordings can never be synonymous with live performances even where the recording is itself of a live performance. Recordings differ from live performances in the way a listener receives them: often alone, perhaps while performing other tasks, and furthermore repeatedly and unchanged. The unchangeability is both a gift and a hindrance. The gift arises from the possibility of re-experiencing and of finding new aspects in something familiar. Yet a listener can be hindered from long-term enjoyment precisely because there is no change. To truly experience music to its fullest may require the existence of auditory signals, audience sounds and possibly visual gestures and body movements from the performers.

Recordings also differ by virtue of the absolute power of a production engineer who may choose to extend, alter, override, or mandate any performance choices. Yet, despite the nature of record production, performance styles on recordings can surely be treated as *proxies* for prevailing playing styles in the wider music performance world at any given time. For example, in the case of published reviews of Brahms sonatas on record, Hong's research indicates that pre-War reviews tended to focus mostly on the specific musical works performed and on the specific performances presented on record.

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<sup>1</sup> For a comprehensive literature review see Gabrielsson, Alf, 'Music MPS research at the Millenium', *Psychology of Music*, 31.3 (2003). See also Bowen's extensive bibliography at: Jose Bowen, 'Bibliography of Performance Analysis' <http://www.josebowen.com/bibliography.html>, Accessed: 11 February 2013.

However, by the 1950s, Brahms reviewers were generally moving towards comparing other performances in their reviews and engaging in objective arguments about performance quality.<sup>2</sup>

Recordings may originate from live performances with minimal production engineering applied to them. In a studio setting, there is unlimited potential to change the resultant sound, to edit at a note level, and to modify all aspects of a performance. The overall sound of a recording is analogous to, but not identical to, live sound even ignoring the quantization compromises of digital audio. A complete absence of audience sounds, may subtly alter human aural depth perception which is also impacted by the loss of higher sound frequencies that have purposefully been filtered out during the recording process.<sup>3</sup> Wide dissemination of recordings may drive an averaging of performance characteristics that were significantly different in earlier periods. For example, the virtual elimination of *portamento* in string sound has been traced both to the realisation that the quality of recorded sound was poor prior to electric microphones becoming commonplace and to changing aesthetic sensibilities.<sup>4</sup> Different aspects of violin bowing technique can affect sounds produced, independently of the instrument itself. There are convincing studies that show that the value of spectral centroid for any performed tone (the average frequency spectrum of the harmonics/formants and the basic tone) has an important effect on perceived timbre and tone quality. Regarding string players, Timmers shows that excessive downward bow force can outweigh variations in tone when playing the lower register of the violin, determining the target tone. This may narrow the bundle of frequencies that is delivered, thus tending to produce duller tone.<sup>5</sup>

It is significant that the sound of a recording is not just a creation by a music performer: it derives from a complex product-engineering process. A record producer has primary

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<sup>2</sup> Hong, Ju-Lee, 'An Empirical Analysis of Musical Expression in Recordings by Selected Cellists' (Masters Dissertation, Goldsmiths, University of London, 2014) <http://research.gold.ac.uk/10156>. Accessed 18 August 2015.

<sup>3</sup> Aden Evens, 'Sound Ideas', in *A Shock to Thought: Expression after Deleuze and Guattari*, ed. by Brian Massumi (London: Routledge, 2002), 184. Evens points out in an endnote (10) that a CD sampling rate of 44.1 kHz theoretically can record frequencies up to 22 kHz. But recording engineers usually filter out all frequencies above 20 kHz. Furthermore, Evens notes that noise, hiss and extraneous sounds can develop in listeners a 'heightened sense of reality'.

<sup>4</sup> Mark Katz, 'Portamento and the Phonograph Effect', *Journal of Musicological Research*, 25.3-4 (2006), 211-32.

<sup>5</sup> Schoonderwaldt, Erwin: 'Mechanics and acoustics of violin bowing', Doctoral Thesis (Stockholm: KTH School of Computer Science and Communication, 2009), 21.

responsibility to manage the engineering of a product that meets the technical requirements of the medium. There are many variables to balance including: length, sound levels, frequency response and amplitude compression. A producer must apply artistic sensibility to the sound that is produced and to the quality of the final product. The complete production pipeline is designed to tailor a final product to the commercial imperatives of a paying audience.

Several researchers argue against music recordings being treated in any way as true sources. Gracyk points to one class of technical objection: he asks if Gould's piano recordings of the *Goldberg Variations* are not important performances irrespective of the fact that they can never again be heard in live performances.<sup>6</sup> His second class of objections is based on the concept that recordings offer what he terms a 'debased acquaintance' breaking the bond between listener and performer. For him, the act of engineering a recording is just as much an act of 'human agency' as the toil of musicians.<sup>7</sup> A third class of objections is grounded in the social dimensions of music. Some, such as pianist Alfred Brendel as quoted by Gracyk, recommend listening only to recordings of live performances, arguing that the musician can perform at his/her best within a dedicated performance space, with intensity heightened by the presence of a live audience.<sup>8</sup> For supporters of the latter proposition, there is a vast trove of recorded music, of many types and instrumentation, available for consumption.

## 2.2 Recording as art

When Glenn Gould relinquished his live performing career for studio recording, which was to become the single target of his music making, he set out to develop superior skills in recording and production technologies. Retiring from the concert hall at thirty-two years of age, he believed that concerts would eventually be replaced by the electronic medium.<sup>9</sup> He wanted fully to share and direct the studio production experience. He transformed his recording procedures to make them a part of his performance timeline, viewing time spent with technologies as part of each performance. This commitment to studio recording was to become, he believed,

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<sup>6</sup> Gracyk, Theodore, 'Listening to Music: Performances and Recordings', *The Journal of Aesthetics and Art Criticism*, 55 (1997), 142.

<sup>7</sup> Gracyk, *Ibid.*, 143-4.

<sup>8</sup> Gracyk, *Ibid.*, 148.

<sup>9</sup> John Cott, *Conversations with Glenn Gould* (Chicago: University of Chicago Press, 1984), 12.

something that other performers should also consider. Starting around 1964, he unleashed a creative storm of recordings but also some fine compositions (including *Opus 1*, and *So You Want to Write a Fugue* that was recorded by the Juilliard String Quartet).<sup>10</sup> Zak writes that record production is ‘creative expression’, with histories and documents, and proposes that

As sound, rather than writing, has become the focus of musical identity, much more of the musical surface has been reified in an interwoven complex of musical syntax, performative utterance, and sonic gesture. Learning to explore the interaction among these elements is a necessary beginning for understanding the compositional concerns of recording teams.<sup>11</sup>

## 2.3 Computation and recordings

Computational modelling of music performances, as in the KTH System, comprises sets of performance rules. Such rules are used by computerized performance software to determine expression and deliberate shaping, from a score’s local to its global contexts. Rules may be empirically tested against human performers, of differing skill levels, to improve their relevance. Recent advances have offered opportunities to study performance variables in real-time: for example, from MIDI instruments and video. These include extensive research into the relationship between micro-timing, structure and perception, tone density shifts (such as a chord preceded or followed by a thinner musical texture) and the impacted ability of listeners to perceive lengthening of intervening time intervals.<sup>12</sup> Other relationships were researched by Krumhansl, using specially designed devices. They include physiological responses during performance and simultaneous ratings of emotional valence.<sup>13</sup> Herein lies a computational opportunity for a feedback loop. Rules may be derived from recordings and fed back into software to generate machine performances from scores. It may be that the outputs are not often as pleasing as human music performances. But that is to miss the value in

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<sup>10</sup> Cott, *Ibid.*, 14.

<sup>11</sup> Albin Zak, ‘The Art of Record Production’, *Journal on the Art of Record Production*, 2007, <http://www.arpjournal.com/asarpwp/the-art-of-record-production/>, Accessed: 15 November 2018.

<sup>12</sup> José Bowen, ‘Tempo, Duration and Flexibility: Techniques in the Analysis of Performance’, *Journal of Musicological Research*, 16 (1996), 111–56. See also Carol Krumhansl, ‘A Perceptual Analysis of Mozart’s Piano Sonata K.282’, *Music Perception*, 13 (1996), 401–32. Also, Bruno Repp, ‘Probing the Cognitive Representation of Musical Time: Structural Constraints on the Perception of Timing Perturbations’, *Cognition*, 44 (1991), 241–81.

<sup>13</sup> Carol Krumhansl, ‘An Exploratory Study of Musical Emotions and Psychophysiology’, *Canadian Journal of Experimental Psychology*, 51 (1997).



trying to understand how performance happens and to continue to reformulate grammars and rules that define performance techniques.

## 2.4 Detecting and comparing

Of increasing interest, are technical researches into similarity measures for automated music matching and retrieval. There has been much useful work in the Music Information Retrieval (MIR) community on techniques for comparing music tracks. Usually limited samples of tracks are measured for similarity of a selection of variables, whether styles, performing artists or meta-data about the actual tracks.<sup>14</sup> Slaney's team examined Echo Nest's audio fingerprinting MIR platform.<sup>15</sup> It is important to note that the latter analysis is concerned with *content-based* retrieval, not with *performance-based* similarity. The team's study developed comparison vectors for up to eighteen variables in popular song recordings as the basis for calculating a similarity metric.<sup>16</sup> The feature vectors included measurements of items such as: mean segment duration, variance of segment durations, attack duration, mean of maximum loudness, estimated tempo, time signature and time-signature stability. They point out that the context of a performance, such as a non-jazz aficionado listening to a jazz recording, has a significant bearing on judgements of similarity. Classifiers based on sampling recording characteristics, such as are provided by Echo Nest, typically ignore possible covariance of variables, although Slaney's paper usefully applied a Mahalanobis distance metric to similarity determinations, which is a metric that does account for covariances.<sup>17</sup>

Shao and colleagues performed data analyses on three multimedia recordings using 32-variable feature matrices. They satisfactorily demonstrated that both systematic random sampling (e.g. every 25<sup>th</sup> element) and simple random sampling may deliver useful results in line with computational approaches involving complete recordings.<sup>18</sup> This is a

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<sup>14</sup> Michael Lorenzi, 'Similarity Measures in the World of Music' (Masters dissertation, Swiss Federal University of Technology, 2007), 10; See also Pampalk, 9.

<sup>15</sup> Now owned by music streaming service Spotify <http://the.echonest.com/>, Accessed: 15 March 2018.

<sup>16</sup> Malcolm Slaney, Kilian Weinberger and William White, 'Learning a Metric for Music Similarity', 2008, 313–18.

<sup>17</sup> Efsthathios Stamatatos and Gerhard Widmer, 'Automatic Identification of Music Performers with Learning Ensembles', *Artificial Intelligence*, 165.1 (2005), 37–56. See article on Mahalanobis Distance at Rick Wicklin, 'What Is Mahalanobis Distance?', *The DO Loop*, 2012 <https://blogs.sas.com/content/iml/2012/02/15/what-is-mahalanobis-distance.html>, Accessed: 15 March 2018.

<sup>18</sup> Jie Shao and others, 'Distribution-Based Similarity Measures for Multivariate Point Set Retrieval Applications' (presented at MM'08, Vancouver, 2008).

particularly important result for this present dissertation since it demonstrates how appropriate reductions in dimensionality and numerosity do not necessarily impair analysis. It is essential to consider strategies to achieve both of these reductions when presented with the volumes of data that might need to be processed for large-scale musical works. Chapter 4 of this dissertation will expand upon the significance of reducing music data for analysis.

In another approach, Banchhor and Khan attempted to automatically detect which instruments were playing within performances, without any prior knowledge of the ensemble.<sup>19</sup> Their study used Zero Crossing Rate (ZCR) of signal energy. ZCR is based on a simple count per constant time interval of the number of times an audio signal has a zero value. It was found that a disadvantage of using ZCR alone as a discriminant for music recordings, is that it may also encompass pitch variations. Lower measures of ZCR may be explained as lower frequencies having lower energies. In addition, the human auditory system does not perceive loudness linearly: loudness curves are frequency-dependent.

## 2.5 Some technical aspects of recording data capture

Data capture from recordings, of all types, faces several difficulties, even with recent advances in software and hardware. While recordings are easy to access, individual performance variables may be difficult to retrieve in any standard way. All recordings should be converted to a common digital storage format to facilitate analysis by software. This ensures a consistent approach on one set of hardware. One important way of capturing detailed music data is by using encoding techniques such as *Musical Instrument Digital Interface (MIDI)*.<sup>20</sup> *MIDI* recordings have the advantage of providing significant details on the notes being played, including onset, attack velocity, volume, pitch, portamento timing and many user-defined and other effects. *MIDI* is not limited to keyboard instruments. However, when performances of interest are historical and the primary sources are old recordings that are not already in *MIDI* format, novel ways are needed for capturing all possible data under consideration, accepting that some variables may never be distinguishable due to the production techniques applied at the time of

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<sup>19</sup> Sumit Banchhor and Arif Khan, 'Musical Instrument Recognition Using Zero Crossing Rate and Short-Time Energy', *International Journal of Applied Information Systems*, 1.3 (2012), 1–4.

<sup>20</sup> The *MIDI* standards are the property of the *MIDI* Manufacturers' Association (MMA), <http://www.midi.org/techspecs/>, Accessed: 14 March 2015.

recording, mastering, or reproduction.<sup>21</sup> Where recordings are in acoustic format (as in long-playing records), even if recorded and/or mastered electronically, they must be converted to digital format. Conversion will lose some information, since digital formats (such as CD, MP3 etc.<sup>22</sup>) are lossy due to the nature of signal quantisation.<sup>23</sup>

Software algorithms may perform complex mathematical calculations, on large volumes of data, to an acceptable level of precision and in a reasonable elapsed time. Data extraction and manipulation are usually straightforward procedures using free, open-source software, although the researcher does need music performance capabilities to complete this work successfully. *Audacity* is fully capable of sound-file capture and editing, both from and to most common formats.<sup>24</sup> *Sonic Analyser* and various audio plugins, from different sources, make the collection of raw data audio files much easier to analyse. It can estimate beat timings and generate tempo graphs.<sup>25</sup> *Tapsnap* can suggest improvements to, and adjust, the manually calculated timings. *Dyn-a-matic* can calculate and normalize decibel sound pressure levels.

The choice of how to store data from that point onwards is important since it may affect retrieval or matching. Canazza and colleagues researched efficient mechanisms for codifying meta-data, data that describes data, to make search and retrieval tasks easier.<sup>26</sup> In other experiments, researchers have used *MIDI* instruments to collect very precise

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<sup>21</sup> Another major advantage of *MIDI* is that instrument channels are completely separated. Fortunately, all of the recordings of the *Phantasy* are post-1950 and use electronic recording and mastering technologies. This means that sound fidelity is high in all cases. However, even stereo recordings bleed the recorded sound across channels, meaning completely automated separation of instruments is not technically possible.

<sup>22</sup> An exception is *FLAC* (Free Lossless Audio Codec).

<sup>23</sup> *Lossy* is defined as ‘Computing (of data compression) in which unnecessary information is discarded’. Oxford English Dictionary, <http://www.oxforddictionaries.com/definition/english/lossy>, Accessed: 26 June 2015. Any digital storage format such as CD, MP3 or OGG needs to represent pitches (and other values) by binary values. Since there is an infinite range of actual values, but only a finite number of binary numbers to represent them, the normal procedure is to define *quanta* to which to assign measured values. Coding/decoding systems (termed CODECs) assign values to the nearest quantum, which may be to the nearest lowest, highest or average.

<sup>24</sup> Audacity Team, *Audacity*, 2013 <http://audacity.sourceforge.net/>, Accessed: 1 January 2013. Chris Cannam, Christian Landone and Mark Sandler, ‘Sonic Visualiser: An Open Source Application for Viewing, Analysing and Annotating Music Audio Files’, in *Proceedings of the ACM Multimedia 2010 International Conference* (presented at the ACM Multimedia 2010 International Conference, New York: ACM, 2010). Craig Sapp, *Tapsnap* (The Mazurka Project), <http://mazurka.org.uk/cgi-bin/tapsnap>. Craig Sapp, *Dyn-a-Matic*, 2009 <http://www.mazurka.org.uk/software/online/dynamatic/>, Accessed: 14 January 2014.

<sup>25</sup> *Sonic Visualiser* and the *VAMP* audio plugins were developed by researchers at the Centre for Digital Music, Queen Mary, University of London.

<sup>26</sup> Sergio Canazza, Antonio Roda and others, ‘Expressiveness in Music Performance: Analysis, Models, Mapping, Encoding’, in *Structuring Music through Markup Languages: Designs and Architectures*, ed. by Jacques Steyn (Hershey PA: IGI Global, 2013), 158.

information as a performance unfolds – utilising technology referred to as the Computer System for Evaluating Music Performance (CSEMP).<sup>27</sup>

There is not yet a general solution to all the problems of IOI detection (and automated tempo calculation) in polyphonic textures. It is particularly difficult to automate beat estimation where a time signature frequently alters since algorithms rely on detecting pressure level changes in the time domain both to identify individual beats and particularly downbeats. Also, automated beat detection can be very poor when applied to complex rhythms, accents and cross-bar phrasings.<sup>28</sup> Cook's research strongly recommends manually developing a beat timing track, for each recording, by listening and tapping. Software, in conjunction with careful listening, may facilitate making fine adjustments following the initial tempo evaluation.<sup>29</sup> While this may appear to hark back to techniques of the 1930s, it produces surprisingly good results and particularly so when applied by musically competent researchers. A significant part of this dissertation covers the software engineering and data management aspects of *Saxify* software developed to use extracted performance data to perform all of the detailed calculations required to compare performances. Software listings and license details are contained in Appendix B. Creation of this software was an integral part of researching the analytical performance model.

Effective performance analysis of recordings of post-1950 music has been quite limited. This means that there is, as yet, no universally accepted best method for measuring and comparing performances. For music of earlier periods, piano rolls provide an effective way of capturing precise timing and dynamics but they are difficult to obtain and to process. Alternatively, MIDI instruments could, where available, capture a complete range of precise performance variables. This is usually done under laboratory conditions. Different approaches, whether analogue or digital, will dictate specific music data and sound processing models. But MIDI data is in short supply, not generally available from commercial sources, and there is no prospect of re-creating commercial recordings in MIDI format.

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<sup>27</sup> *Guide to Computing for Expressive Music Performance*, ed. by Alexander Kirke and Eduardo Miranda (London: Springer, 2013), 2.

<sup>28</sup> Widmer *et al.*, *Ibid.*, 118.

<sup>29</sup> Nicholas Cook, 'Methods for Analysing Recordings', in *The Cambridge Companion to Recorded Music*, ed. by Nicholas Cook and others (Cambridge: Cambridge University Press, 2009), 221–45.

## 2.6 Chapter summary

A significant body of research was undertaken at CHARM on methods and an overall philosophy for analysing recordings.<sup>30</sup> Extracting performance variables from recordings is not universally straightforward and relative variations are often a more reliable metric than absolute ones.<sup>31</sup> The researcher faces firstly the problem of deciding which variables to measure. Some features of a recording may be more important than others in defining similarity. The researcher must decide on how to apply a weighting scheme to the multivariate analysis. This is followed by the data measurement tasks and, as shall subsequently be explained, a choice of appropriate analytical techniques.

Choice of the measurement interval, whether bar, beat or sub-division of beat, needs to be justified, while recognising that music provides continuous signals that must be discretized. This may be achieved on the basis that inaccuracies, due to measurement error as might be caused by capturing data at too low a level, may be reduced.<sup>32</sup> Capturing fast-moving musical data in real-time is undoubtedly easier by using larger timing intervals.

The following chapter contains a background to the history and structure of Schoenberg's *Phantasy for Violin with piano accompaniment*, op. 47. This work forms the basis for the central case study of this dissertation which concerns the application of the *Saxify* model.

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<sup>30</sup> <http://www.charm.rhul.ac.uk/index.html>, Accessed: 24 June 2015.

<sup>31</sup> Renee Timmers, 'Vocal Expression in Recorded Performances of Schubert Songs', *Musicae Scientiae*, 11.2 (2007), 4.

<sup>32</sup> Renee Timmers, Henkjan Honing, 'On Music Performance, Theories, Measurement and Diversity', *Cognitive Science Quarterly*, 1 (2002), 12.

## CHAPTER 3 | SCHOENBERG'S *PHANTASY*, OP. 47

Schoenberg finished the violin part of his *Phantasy for Violin with piano accompaniment*, Op. 47 on March 22, 1949 and the piano part a week later. The premiere was on September 13, 1949.<sup>1</sup> It was published posthumously—initially in 1952, and again in 1978 with corrections. The work was commissioned by, and dedicated to, violinist Adolf Koldofsky who had formerly been a pupil both of Belgian Eugène Ysaÿe and Czech Otakar Ševčík. It has been suggested that Schoenberg composed the violin part first and followed later with the piano part, very much in the role of accompaniment.<sup>2</sup> This separate composition of the parts may be significant to a performing interpretation in the sense that the piano player at times supplements and at others complements component parts of a whole, with Schoenberg often sharing, or echoing, elements of the row vertically into the piano part.<sup>3</sup>

The *Phantasy* is short—466 bars requiring between 8 and 11 minutes in performance—and structured in a series of dance-like, highly contrasting sections, using varying combinations of tempo, metre, and rhythmic effects that differentiate sections on an affective basis.

Schoenberg was very concerned with placing all of his music within a broad historical context, seeing his twelve-tone works on a continuum from Brahms and other late-nineteenth century Romantic composers. He worked particularly hard to absorb compositional principles, such as continuously developing variation, rather than merely aping sounds of the past.<sup>4</sup> Many of his early tonal compositions, such as his String Sextet, *Verklärte Nacht*, op. 4, were positioned in a late-romantic mould. He continued, in later life, to see his new twelve-tone compositional technique as exhibiting enhanced chromaticism, *pantonality* encompassing all keys, rather than *atonality* possessing no key. Yet, as early as 1930, he began to believe himself to be alienated from the musical

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<sup>1</sup> Therese Muxeneder, 'Research Note' (Arnold Schönberg Center, 2018) <https://www.schoenberg.at/index.php/de/joomla-license-sp-1943310035/phantasy-for-violin-with-piano-accompaniment-op-47-1949>, Accessed 21 December 2018.

<sup>2</sup> Larry Polansky, 'History and the Word: Form and Tonality in Schoenberg's *Phantasy* for Violin with Piano Accompaniment', *Ex. Tempore*, 3.1 (1985), 30.

<sup>3</sup> Lisa Tipton, 'Schoenberg's "Phantasy" Form' (Doctor of Musical Arts Dissertation, City University of New York, 2017), 65.

<sup>4</sup> Walter Frisch, *Brahms and the Principle of Developing Variation* (Berkeley: University of California Press, 1984), 170.

public, chiefly because he did not perceive any significant interest in his twelve-tone music despite increasing scholarly interest. This was particularly so in the United States where he had moved, aged sixty, to escape persecution of Jewish intellectuals in Europe.<sup>5</sup> Following his emigration to Los Angeles, Schoenberg rebuilt his musical self-confidence by undertaking a heavy schedule both of public lectures and of teaching composers associated with the Los Angeles film industry including Leonard Rosenman and fellow refugee Hanns Eisler.<sup>6</sup>

The *Phantasy* demonstrates mastery of, and supreme self-confidence in, his twelve-tone technique. The brevity of its sections, together with clear structural contrasts, help to generate a sense of coherence in the *Phantasy*'s continuous music while allowing each one to stand alone. Adorno wrote of this work that the 'radically-dynamic process of composition itself results in a composition in co-ordinated fields' indicating that the individual parts of the work, although appearing quite distinct, balance each other.<sup>7</sup> For Adorno, reductive methods are not suited to analysing 'new music' precisely because such methods do not take into account the individuality of sections of a work and the necessity to treat sections both separately and as components of a whole. This is Schoenberg's conception of musical fantasy:

it is in contradistinction to logic, which everyone should be able to follow, favours a lack of restraint and a freedom in the manner of expression, permissible in our day only perhaps in dreams. In dreams of future fulfilment; in dreams of a possibility of expression which has no regard for the perceptive faculties of a contemporary audience.<sup>8</sup>

We know that Schoenberg's later works handle the rules of twelve-tone composition flexibly. His *Phantasy*, op. 47 and *Quartet No. 4*, op. 37 have even been viewed as 'new beginnings' in respect of their 'withdrawal of complex contrapuntalism and the fragmentary, almost labyrinthine, shaping of form'.<sup>9</sup> Covach quotes Krenek:

It is the belief of the author [Krenek] that, at a later stage of development, atonal music may not need the strict regulations of the twelve-tone technique. He anticipates that the essentials of this technique will grow into a sort of second nature. This consummation, however, will materialize only if the twelve-tone technique is constantly used as a training in the atonal

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<sup>5</sup> Marcia Citron, *Gender and the Musical Canon*, Paperback (Urbana: University of Illinois Press, 2000), 29.

<sup>6</sup> Crawford, Dorothy, 'Arnold Schoenberg in Los Angeles', *The Musical Quarterly*, 86 (2002), 6–48.

<sup>7</sup> Adorno, Theodor, 'On the Problem of Musical Analysis', trans. by Max Paddison, *Music Analysis*, 1 (1982), 181.

<sup>8</sup> Arnold Schoenberg, *Style and Idea: Selected Writings of Arnold Schoenberg*, ed. by Leonard Stein, trans. by Leo Black (London: Faber and Faber, 1975), 274–75.

<sup>9</sup> Gianmario Borio, 'Work Structure and Musical Representation: Reflections on Adorno's Analyses for Interpretation', trans. by Martin Iddon, *Contemporary Music Review*, 26.1 (2007), 58.

idiom, just as the theory of classical harmony is taught as an introduction to “free tonal” composition.<sup>10</sup>

### 3.1 Two versions of the score

There are two performing editions of the score.<sup>11</sup> The 1978 edition incorporates eighteen editorial pitch changes from the first, 1952 edition.<sup>12</sup> Editorial corrections in the later edition correct note-spelling and copying errors in the composer’s original manuscript, except for one parenthesized metronome marking,  $\text{♩}=46$ , at bar 34 in the 1978 edition: it is not written in Schoenberg’s hand on the facsimile but, according to the editor, had been authorized by him. Schoenberg suffered from triskaidekaphobia, fear of the number 13, so there is no bar numbered 13 in the *Phantasy*. Instead he numbered bar 12 as 12a, followed by a 12b and then a 14.

Performance comparisons for any musical composition should consider any possible effects arising from performers using different score versions. For present purposes, since differences between the two editions of the *Phantasy* are restricted solely to pitch corrections in single notes or dyads and a single tempo marking, a performer’s choice of either score edition is unlikely to be a significant factor in differentiating performance variables (other than pitch). Performances prior to 1978 must have used either the 1952 published version or a copy of the composer’s facsimile (which is now in the Schoenberg Archive, Vienna).<sup>13</sup> Pre-publication scores were used for the first 1949 live performances, together with the 1951 Koldofsky-Steuermann and the 1951 Varga-Krenek recordings.

### 3.2 Sources of recorded performances

Research identified forty-four recordings of the *Phantasy*, which are listed in the Discography. The starting point was Wayne Shoaf’s pre-existing Schoenberg discography of thirty-three recordings.<sup>14</sup> The following criteria were established for selecting additional performances to extend Shoaf’s work, not least to ensure attribution and inform consistency of performance standard. Each recording was checked to be: (a)

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<sup>10</sup> John Covach, ‘Dahlhaus, Schoenberg and the New Music’, *In Theory Only*, 12.1–2 (1991), 29.

<sup>11</sup> Arnold Schoenberg, *Phantasy for Violin with piano accompaniment* (New York: Peters, 1952) and Arnold Schoenberg, *Phantasy for Violin with piano accompaniment* (New York: Peters, 1978) annotated by renowned Polish-American violinist Roman Totenberg. Musical examples quoted in this dissertation are from the 1952 edition.

<sup>12</sup> See the list of changes in Appendix E.

<sup>13</sup> See Appendix C for a copy of the facsimile score.

<sup>14</sup> Wayne Shoaf, *The Schoenberg Discography*, 2nd edn (Berkeley: Fallen Leaf Press, 1994).



commercially published on LP or CD/DVD; or (b) recorded live and attributed by a reputable source; or (c) published online where it was subjectively evidenced that the performers were performing at or beyond conservatory diploma level (the *Phantasy* has clearly virtuosic elements that require both performers to exhibit advanced performance technique). While there is an element of subjectivity to this latter criterion, performing the *Phantasy* sets a sufficiently high performance bar, for both violinist and pianist, as to make it straightforward to decide if a performance merits inclusion.

### 3.3 Structure of the *Phantasy*

Schoenberg loved dance music, old waltz rhythms and Johann Strauss's compositions. Like Berg, he was insistent that a performer should observe the tiniest detail in seeking to perform his music. Only after perfecting the minutiae should a performer, in his view, feel liberated to create an interpretation. The terminology of Sonata Form may be used to describe sections of the *Phantasy's* 166 bars (comprising seventeen individual tempo markings as noted by Raab).<sup>15</sup>

Successful performance of any music requires both performers and listeners to interpret structures. It will be demonstrated in later chapters how expressivity flows across the complete *Phantasy*, and how it is surprisingly similar in different performances given the span of time and the variety of performers. Interpretation covers many aspects of performance, including at least: physical, gestural, sonoristic, social, aesthetic, physiological and cognitive domains. Polansky's well-argued view is that any analysis that is made purely on the basis of row, motif or harmony is limited. Of equal value in perceiving the structural makeup of any music work must be 'motive and morphology, rhythm, temporal density, dynamics and timbre'.<sup>16</sup> Different approaches highlight the ambiguity of cadential boundaries and phrase structures in such complex music, compounding the difficulties of developing a convincing interpretation. Rudolf Kolisch, a rare left-handed violinist, was renowned for learning and analysing music away from his violin. This, according to Westell, facilitated Kolisch's complete focus on large-scale form leaving local performing details until later. Examination of Kolisch's

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<sup>15</sup> Claus Raab, "'Fantasia Quasi Una Sonata'. Zu Schonbergs 'Phantasy' for Violin with Piano Accompaniment Op.47", *Melos/Neue Zeitschrift Fur Musik*, 2.3 (1976), 191–96.

<sup>16</sup> Polansky, *Ibid.*, 33.

rehearsal score markings show that he often used very unconventional fingerings to smooth specific shifts ‘in order to not disrupt musical gestures’.<sup>17</sup>

Scholars have described the structure of this work in very different ways.<sup>18</sup> In his liner notes to a 1969 recording of the *Phantasy*, Leonard Stein (who had acted as teaching assistant to Schoenberg from 1939 to 1942) identifies four top-level sections and a coda: he terms them *generally dramatic* (31 bars), *mostly lyrical* (53 bars), *form and character of a scherzo* (48 bars) and *main section condensed* (21 bars), *with coda* (13 bars).<sup>19</sup> This is in contrast to Lester’s suggestion that the form of the *Phantasy* is of a dance-like baroque *partita* with sectional variations.<sup>20</sup> According to Feisst, the *Phantasy* ‘fleetingly suggests such traditional structural principles as sonata and sonata form and nostalgically summons the Viennese *waltz* and Austrian *ländler*’ harking back to some music of Schoenberg’s early period in Vienna.<sup>21</sup> Whittall sees a collection of brief sections that are ‘splintered, offering “fragmentary impression”’ and quotes Adorno: who wrote of Schoenberg’s rejection of ‘a fully constructed totality ... he longs simply to let himself go’.<sup>22</sup> Hasty takes a more holistic view. For him, the *Phantasy* manages to ‘unite the shock of discontinuity with glimpses of a wholeness in which the most diverse characters can succeed each other without confusion’.<sup>23</sup>

Tipton examined research by Lewin, Polansky, Rufer and Lester as well as Stein’s proposal. Lewin locates a 23-bar reprise commencing at bar 143. Rufer offers a ‘free form’ interpretation of the middle sections even if his overall structure is ABA with a final coda that starts at bar 136. Lester does convincingly relate his formal analysis of the *Phantasy* to suggestions for performing it.<sup>24</sup> He shows how the separate violin and piano parts interact in both rhythmic and compositional motifs throughout the work,

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<sup>17</sup> Emily Westell, ‘Reconsidering Conventional Techniques in the Performance of the Violin Music of the Second Viennese School’ (Schulich School of Music, McGill University, 2011), 26-7.

<sup>18</sup> David Lewin, ‘A Study of Hexachord Levels in Schoenberg’s Violin Fantasy’. See also Larry Polansky, ‘History and the Word: Form and Tonality in Schoenberg’s *Phantasy* for Violin with Piano Accompaniment’, *Ex. Tempore*, 3.1 (1985), 29–40.

<sup>19</sup> *Ars Nova/Ars Antiqua* AN 1002 (1969).

<sup>20</sup> Joel Lester, ‘Analysis and Performance in Schoenberg’s *Phantasy*, Op. 47’, in *Pianist, Scholar, Connoisseur: Essays in Honor of Jacob Lateiner*, ed. by Bruce Brubaker and Jane Gottlieb, Festschrift Series, 15 (Pendragon Press, 2000), 155.

<sup>21</sup> Sabine Feisst, *Schoenberg’s New World: The American Years* (Oxford: Oxford University Press, 2011), 79.

<sup>22</sup> Arnold Whittall, ‘Schoenberg since 1951: Overlapping Opposites’, *The Musical Times*, 142.1876 (2001), 17. See also Adorno, Theodor, *Quasi Una Fantasia: Essays on Modern Music*, trans. by Rodney Livingstone (London & New York: Verso Classics, 1994), 152-3.

<sup>23</sup> Hasty, *Ibid.*, 461.


















<sup>24</sup> Lester, *Ibid.*, 155.

providing some highlights onto larger scale structures as well as on local phrasing. Both he and Polansky agree that Schoenberg maintains a consistent relationship between the hexachords of the row between violin and piano.<sup>25</sup>

Table 3.1 below compares four alternative views that were selected because of the level of detail the authors proposed on structure. Their proposed sections are indicated under their names in the leftmost columns.

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<sup>25</sup> Lester, *Ibid.*, 157.

Sections				Score	Start bar	End bar	Time Signature	Tempo
Polansky	Lester	Stein	Tipton					
A	A	A	A	Grave I	1	6	4/4	 = 52
				II	7	8	3/4	 = 52
				III	9	10	4/4 & 3/4	 = 52
				IV	11	24	3/4 & 4/4	 = 52
				Più mosso, furioso	25	31	4/4	 = 80
		B		Poco meno mosso	32	32	5/4	 = 80
				II	33	33	4/4	 = 80
	B		B	Meno mosso	34	39	3/4	 = 80
				Lento	40	51	3/4	 = 46
				Grazioso	52	63	9/8	 = 56
				Tempo I	64	71	4/4	 = 52
				Più mosso	72	84	4/4	 = 52
B		C	B'	Scherzando	85	92	6/8	 = 112
				Poco tranquillo	93	116	6/8	 = 112
				Scherzando	117	134	6/8	 = 112
		A'		Meno mosso	135	153	6/8	 = 70
A'	A'		A	Tempo I	154	166	4/4	 = 52

*Table 3.1 Structural Map of the Phantasy – four alternative viewpoints*

### 3.4 Phrasing

The *Phantasy* is not easily approached in terms of small-scale phrasing since the composer phrased the score only intermittently. Within a short work of 466 beats, over the course of Schoenberg's 166 bars, there is an extraordinary variability of tempi, rhythms and time signatures, all of which can cross section boundaries. Cadence is often implied rather than expressed, by reference to normal expectation at segment boundaries

There is a very clear phrase-final cadential gesture at bar 24, shown in Ex. 3.1. The *fermata* marks the end of the first section with the pianist dwelling on the low G♯ before both instruments launch the somewhat surprising *Più mosso, furioso*.

24

Vln. *G.* *mf*

Pno. *pp* *con sord.* *molto rit.*

**Piu mosso**  
♩ = 80 *furioso*

*p* *cresc.*

Given Schoenberg's reverence for, and musical development upon, late nineteenth-century styles, it is unsurprising that he composed music that is often reminiscent of Brahms's lyrical style. Arnone commented that Brahms was a master of 'subversion of the boundaries between melody and accompaniment', understanding perfectly the sonorities achievable on pianos of his time.<sup>27</sup> The similarities are evident in Ex. 3.2 between the flowing piano writing in the *Phantasy* at bar 35 (*cantabile*) and the opening bars of Brahms's piano *Ballade* Op. 10 No. 4 (*Andante con Moto, espressivo*). The melodies in both are prolonged above a quaver accompaniment. Both piano accompaniments exhibit a similar span from treble to bass, demonstrating what are typically Brahmsian sonorities.

<sup>27</sup> Augustus Arnone, 'The Aesthetics of Textural Ambiguity: Brahms and the Changing Piano', *Current Musicology*, 82 (2006), 24.



Ex. 3.2 Schoenberg (top) and Brahms

### 3.5 Fundamental motifs

It is beyond the scope of this dissertation to perform a detailed analysis of the *Phantasy*. A limited overview of the tone row and motifs will suffice.

The two hexachords of the *Phantasy*'s row are stated fully across the opening two bars of the piece as follows:



Ex. 3.3 Two hexachords of the row,  $H_0$  and  $H_1$

$H_1$  is seen to be a transposed inversion of  $H_0$  as shown in Table 3.2 below (directions of semitone shifts are indicated by arrows):

Semitones	$H_0$	Inverted Semitones	Transposed inversion $H_1$
-	B $\flat$	-	E $\flat$
1 $\downarrow$	A $\natural$	1 $\uparrow$	E $\natural$
4 $\uparrow$	C $\sharp$	4 $\downarrow$	C $\natural$
2 $\downarrow$	B $\natural$	2 $\uparrow$	D $\natural$
6 $\downarrow$	F $\natural$	6 $\uparrow$	A $\flat$
2 $\uparrow$	G $\natural$	2 $\downarrow$	G $\flat$

Table 3.2 Relationship of the 2 hexachords

There are two recurring compositional motifs, both introduced in the first complete bar: a short-long rhythm (marked '1' in Ex. 3.4 below) which is immediately followed by a short-short-short one (marked '2' also in Ex. 3.4). The two motifs are emphatically repeated throughout the piece. Polansky points out that Schoenberg alters  $H_0$  in the violin part and partially unfolds  $H_1$  into the piano part.<sup>28</sup> Schoenberg uses diminished and augmented triads, in a similar manner to Bach in his *Fantasias*, to develop harmonies that 'neither in its entirety nor even in its detail can be easily referred to a key'. Many years previously Schoenberg wrote that such types of chord can belong to any key reinforcing the *pantonality*.<sup>29</sup>

Since so many other composers have encoded names in musical works, it is my personal observation that the rhythmic representation of the opening notes, being the Morse Code sequence dot-dash/dot-dot-dot, represents the alphabetic 'A S', Arnold Schoenberg.

The image shows a musical score for a violin and piano. The tempo is marked 'Grave (♩ = 52)'. The violin part (Vln.) is in treble clef, and the piano part (Pno.) is in grand staff. Two rhythmic motifs are highlighted with red circles and numbered. Motif 1 is a short-long rhythm (quarter note followed by a half note) in the violin. Motif 2 is a short-short-short rhythm (three eighth notes) in the piano. The piano part also features a 'passionato' marking and a 'sf' (sforzando) dynamic.

Ex. 3.4 Two rhythmic motifs in the parts

Schoenberg unfolds variations on these two highly rhythmic motifs in a very flexible way. He attempts to make the work comprehensible to listeners by making recognisable connections between similar musical ideas: creating what Zbikowski refers to as *coherence*.<sup>30</sup> The opening rhythmic motifs, developed in various ways, remain prominently recognisable throughout the work. The piano often fills in asynchronously with variants of the violin rhythm, as seen in Ex. 3.4 above, where it anticipates the *staccatos* of the upper part. The motifs do not always recur together and are sometimes

<sup>28</sup> Polansky, Larry, 'History and the Word: Form and Tonality in Schoenberg's Phantasy for Violin with Piano Accompaniment', *Ex. Tempore*, 3 (1985), 29–40, Section II. And see David Lewin, 'A Study of Hexachord Levels in Schoenberg's Violin Fantasy', *Perspectives of New Music*, 6.1 (1967), 18–19.

<sup>29</sup> Schoenberg, Arnold, *Style and Idea: Selected Writings of Arnold Schoenberg*, ed. by Leonard Stein, trans. by Leo Black (London: Faber and Faber, 1975), 274.

<sup>30</sup> Lawrence Zbikowski, 'Musical Coherence, Motive and Categorization', *Music Perception*, 17.1 (1999), 7.

rhythmically transformed. An example of this is shown by the broadening of the second motif into triplet quavers in Ex. 3.5, where *a tempo* is marked:

The image shows a musical score for violin (Vln.) and piano (Pno.) in 4/4 time. The violin part has a melodic line with a motif that broadens into triplet quavers, marked 'a tempo'. The piano part provides accompaniment with various dynamics like *f*, *fp*, and *p*. The score includes bar lines and dynamic markings.

Ex. 3.5 Rhythmically altered motifs in violin part (bars 19-20)

Both motifs evolve further in Ex. 3.6, the second one broadening into more leisurely, three-to-a-beat quavers in the Violin part, accompanied by a chattering, busy, staccato piano figuration at bar 52:

The image shows a musical score for violin (Vln.) and piano (Pno.) in 9/8 time, titled 'Grazioso (♩ = 56)'. The violin part features a motif that broadens into more leisurely, three-to-a-beat quavers. The piano part provides accompaniment with a chattering, busy, staccato figuration. The score includes bar lines and dynamic markings.

Ex. 3.6 *Grazioso* version

McDonald also refers to this idea of musical *coherence* as a quality of the *Phantasy* that arises from Schoenberg's application of rhythmic similarities that maintain connecting, aural threads of comprehension for a listener.<sup>31</sup> This can be seen at the *Poco Meno Mosso* section starting at bar 32, shown in Ex. 3.7, where the composer echoes the same rhythmic motif between parts. This time he requires both to commence *dolce*, following with a transformation of the violin part into a beautiful *cantabile* melody.

<sup>31</sup> Malcolm MacDonald, *Schoenberg*, 2nd edn (Oxford: OUP, 2008), 225.



**Poco meno mosso**

**Meno mosso**

*Ex. 3.7 Short-short-short long motifechoed dolce*

The *Phantasy* concludes with a short coda that returns to the original tempo and a final high-position flourish.

### 3.6 Chapter summary

This chapter has placed the *Phantasy* in the context of its time, examined several competing theories as to its structures, and demonstrated the variety within such a short work. My intention is to use the competing structural theories to test how performers deliver expressive effect on a global scale; that is, across a complete performance. This will rely upon comparisons of each section of the *Phantasy*, across all performances, as mapped by the theorists.

It shall be demonstrated in Chapter 7 how performance maps may be constructed, using the data in Table 3.1, for *Saxify*.<sup>32</sup>

<sup>32</sup> Tipton, *Ibid.*, 37.

## CHAPTER 4 | EXPERIMENTAL METHOD

This chapter describes *Saxify*, the performance analysis model developed as part of the research for this dissertation. Development of the model, including designing the approach, coding the software programs, obtaining the recordings and generating the measurement data, took place over an eighteen-month period and involved significant software prototyping and research into prior computational approaches. In addition, the chapter includes a detailed discussion of the sequential steps involved in applying this model to a set of recorded performances (for which complete software listings are provided in Appendix B). Section §4.14 below contains a detailed description of the *Saxify* model and how it may be applied in practice. The calculations are performed in two distinct areas: (1) within an Excel spreadsheet that is designed to create the PN, and (2) in programs running in the R statistical language, which is particularly suited to solving problems that require a high level of numerical calculations. Furthermore, the Excel spreadsheet has an important role in acting as a store of the musical data used by the R programs. It should be noted that the R code listings contain substantial indicative comments that show the meaning of specific sections of the programs, and indicate why particular instructions are included.

Several researchers have addressed issues of defining melodic similarity/dissimilarity, primarily in areas as diverse as automated music information retrieval, whale song comparisons and ‘query by singing/humming’.<sup>1</sup> The goals were primarily to match musical extracts on the basis of musical content without considering differences between performers or performances. This dissertation, however, is concerned primarily with assessing multiple performances of the same musical material, specifically assessing degrees of performance difference: there are many issues to be resolved in

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<sup>1</sup> Alan Marsden, ‘Interrogating Melodic Similarity: A Definitive Phenomenon or the Product of Interpretation’, *Journal of New Music Research*, 41 (2012), 323–4. See also Naresh Vempala and Frank Russo, ‘An Empirically Derived Measure of Melodic Similarity’, *Journal of New Music Research*, 44.4 (2015), 391–92, Maarten Grachten, Josep Arcos and Ramon Lopez de Mantanaras, ‘Melodic Similarity: Looking for a Good Abstraction Level’, in *Proceedings of 5th International Conference on Music Information Retrieval* (presented at the ISMIR 2004, Barcelona: Carnegie Mellon University, 2004), Rainer Typke, Frans Wiering, and Remco Veltkamp, ‘Symbolic Melodic Similarity and Query by Singing/Humming’ (presented at the MIREX. 2006 (at ISMIR 2006), Victoria, BC, 2006). See also Allen, Jenny, Anita Murray, Michael Noad, Rebecca Dunlop, and Ellen Garland, ‘Using Self-Organizing Maps to Classify Humpback Whale Song Units and Quantify Their Similarity’, *Journal of the Acoustical Society of America*, 142 (2017), <https://doi.org/10.1121/1.4982040>

establishing how far any performance diverges from a common baseline or from another performance. The initial consideration is to try to understand the factors by which performances might differ. It is straightforward to compare performances if global performance tempo is the only variable. Yet music performances, certainly by highly-skilled musicians, differ on a potentially wide range of other variables.

Most of my experimental research would have been very difficult in the pre-computer age, and indeed, even until quite recently. Computer software can be used judiciously to reduce the amount of repetitive manual effort that may be involved in audio signals research. Even more significant than reducing manual effort, software may perform calculations to any arbitrary level of accuracy and do so reliably and repeatedly. For these reasons, software algorithms lie at the heart of the proposed experimental method. The focus in this chapter is on what the algorithms are designed to achieve and how those achievements are musically important.

Encompassing the nature of expressive performance characteristics in an analytical model is a worthy goal. As noted previously, there are possible benefits to be gained from a reasoned explanation of how expressivity relates to different performances. The study of performances can benefit from pushing the boundaries of how expressivity is created, not just in respect of localized tempo and dynamics but also other subtle instrument-specific techniques that affect timbre. It is proposed herein that listeners can engage better with unfamiliar music by gaining an understanding of how performers are attempting to communicate. This may involve how performers express musical structure as well as the specific techniques being applied. Schoenberg and others have somewhat optimistically proposed that educated, repeat listening leading to some degree of memorisation is an efficient way to improve musical understanding.<sup>2</sup> Milton Babbitt famously offered the contrarian proposition that

the time has passed when the normally well-educated man without special preparation could understand the most advanced work in, for example, mathematics, philosophy, and physics. Advanced music, to the extent that it reflects the knowledge and originality of the informed composer, scarcely can be expected to appear more intelligible than these arts and sciences to the person whose musical education usually has been even less extensive than his background in other fields.<sup>3</sup>

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<sup>2</sup> Arnold Schoenberg, *Schoenberg's Program Notes and Musical Analyses*, ed. by J. Daniel Jenkins, *Schoenberg in Words* (Oxford: OUP, 2016), 5, 5.

<sup>3</sup> Milton Babbitt, 'Who Cares If You Listen', *High Fidelity*, 1958.

He seemed to be arguing that serialism, like advanced mathematics, was too difficult for the lay person to appreciate—even though the extremes of total serialism were to wither within a short time of his article. Yet, rather like Schoenberg, he may have simply been pointing to a need to study such music in depth before its significance could be understood. Whereas advanced music performers have already developed their performance techniques, younger learners need to understand how expressivity can be developed—on a local basis and subsequently shaped across an entire performance. This is one reason for adopting an empirical approach to measuring it.

There are additional reasons for adopting the approach proposed herein: applications of mathematics and of software tools and quantitative techniques to performance analysis of music offer aspects worthy of exploration, no less significant than applications in other domains of human knowledge.<sup>4</sup> Areas as diverse as medical science, economics, psychology, earth science, bio/life-sciences, medicine and chemical engineering have long benefitted from sophisticated multivariate approaches that are appropriate to those individual disciplines. There is no reason to reject technological methods where judiciously applied to music. Only a few performance variables have been addressed by musicologists (typically tempo and dynamics) precisely because such tools were, historically, very limited. It also seems clear that one limitation of analytical models has been their ability to incorporate additional variables, such as the harmonic structure of pitch/intonation (as created by different string players) or the many varieties of instrument-specific articulation. While *Saxify* today does not incorporate these variables, it can easily be enhanced to do so and I will discuss this in the final Chapter of this dissertation.

Several aspects of musical performance combine to make conventional statistical analysis difficult for large-scale works scored for multiple instruments. Music data may be voluminous and involve many different variables for which statistical analysis may help. But the significant problems of ‘big data’ may apply as in many other fields. Comparisons between individual multivariate datasets are difficult to perform and are not straightforward to comprehend. The more characteristic variables that are added to a model, the greater become the difficulties of analysis. Musical performance has many characteristics but there is limited capacity of the human mind to visualize structures or

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<sup>4</sup> For example see the AHRC Research Centre for the History and Analysis of Recorded Music (CHARM) at <http://www.charm.rhul.ac.uk/index.html>, Accessed: 20 October 2015.

meanings in higher dimensions. It is inevitable that the probability increases of finding random relationships within a large mass of multi-dimensional data. This may lead to detecting relationships that have no meaning or consequence in the real world. A researcher might thus develop ill-informed threads of an argument that drift far from initial objectives, towards unjustifiable conclusions.

A *scientific method*, on the other hand, relies on twin principles of *falsifiability* and *verifiability*.<sup>5</sup> The empiricist attempts to falsify a pre-formulated *null hypothesis*, termed  $H_0$ , which is usually stated in terms of *no change or difference*. It is important that a testable hypothesis be formulated in advance of experimentation. Empiricism characterises *Saxify*, the performance analysis model used/applied in this dissertation.<sup>6</sup> Where the data fail to falsify  $H_0$ , one may presume that evidence has been found that supports it. Yet no empiricist may ever claim a proof on purely evidential grounds. Musicology may never benefit from arguments constructed on the basis of inappropriate mathematics. It can surely support principles of minimal complexity while taking maximal advantage of relevant tools and techniques developed in other disciplines. In musical terms, a model at minimum explains and determines what is an *average* performance, measures a conceptual *dissimilarity* between pairs of recorded performances, and identifies areas of a performance that contribute most to a difference.

$H_0$ , the *null hypothesis*, having been formulated, the broad procedure from this point forward is to attempt to falsify it. Ultimately, one might wish to make statements such as ‘Performance A is no further from the average than Performance B’, or ‘Performance A’s first movement is performed very similarly to Performance B’; or, an alternative hypothesis: ‘Performance C is so far from the average as to be considered an outlier that should be subject to independent study to determine why it is so different’. In the most general sense, a musical performance will comprise vast amounts of data such that computation can be a significant challenge. If a model, or system, requires significant computational time to reach simple conclusions, then it could be preferable to choose more straightforward, or non-numeric methods. The concept of a *Performance Fingerprint* is similar to a human one. There is a theoretical set of characteristics which

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<sup>5</sup> Karl Popper, *The Logic of Scientific Discovery* (London: Routledge, 2002), 17-18. First published (1934) as *Logik der Forschung*. Re-written and substantially translated to English by Popper with assistance from Julius Freed and Lan Freed (1959) and published by Hutchinson. See also Popper, *Ibid.*, 24 for ‘a subjective experience, or a feeling of conviction, can never justify a scientific statement’

<sup>6</sup> Gerhard Widmer and Werner Goebbbl, ‘Computational Models of Expressive Music Performance: The State of the Art’, *Journal of New Music Research*, 33 (2004), 203.

uniquely identify a performance. Yet the full set is rarely available, and possibly not even knowable. We must rely on a balance of probabilities to make an identification, given a subset of the possible combinations of variables. Modifications to *tempi* and *dynamics* are known determinants of expressivity. I chose to also examine the point rates of change of those variables since these may highlight some more subtle expressive effects.

A musical score is ‘music as writing’, a text, and it also serves as a guide to performance, accepting that some composers have been less and some more prescriptive on the role of scores.<sup>7</sup> A score is unlikely to provide all information necessary for performance and should not be expected to resolve all ambiguities of structure, harmonic intent, motif development or rhythm.<sup>8</sup> Some composers provide very limited information. Successful performance of music requires a musician to interpret both higher-order structures as well as fine-grained detail. There are multiple simultaneous activities required including physical execution, gesture, acoustic rendering, social interaction, aesthetic/artistic interpretation and communication, physiological processes and cognition. All of these and probably more contribute to the fact that each performance will differ from all others. The aim of *Saxify* is to capture a performance fingerprint, to detect the overall degree of dissimilarity between any pair of performances, accepting that *dissimilarity* is a relative term, for which there can be no absolute value in musical terminology.

#### 4.1 Data representation

There are many approaches to representing multi-variate time series of which two are: Fourier transforms (*Fourier analysis* methods represent a time series as a set of trigonometric functions that decompose complex waveforms into component series) and wavelets.<sup>9</sup> Data science researchers have proposed symbolic representations that can benefit from advances in text processing and text mining—and it is symbolic approximation that I have chosen as an appropriate way to build a performance model. A common goal is to develop a representation that is useful for general data mining,

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<sup>7</sup> Nicholas Cook, *Beyond the Score: Music as Performance* (Oxford: Oxford University Press, 2013), 1.

<sup>8</sup> Jan Beran and Guerino Mazzola, ‘Analyzing Musical Structure and Performance—A Statistical Approach’, *Statistical Science*, 14 (1999), 50.

<sup>9</sup> Bloomfield, Peter, *Fourier Analysis of Time Series* (New York: John Wiley & Sons, 2000), p. 2. See also <http://www.polyvalens.com/blog/wavelets/theory/#7.+The+scaling+function+%5B7%5D>, Accessed: 15 May 2018.

such as searching for specific data in a large series or matching two series. Another interesting problem is so-called anomaly detection which seeks parts of a time series that contain anomalous or novel data. In a multi-variate time series, such as time-based measurements of the human heart, this approach can be used to detect patterns of behaviour that span variables of interest. The parallels with music performance should be clear. A *performance motif* is some characteristic pattern in a combination of performance variables such as tempo and dynamic level. A *compositional motif* is a pattern in a score that may vary but is substantially easier to detect by careful reading than is listening for *performance motifs*. This problem can be targeted by symbolic analysis, although this dissertation does not take on this particular challenge.

## 4.2 Saxify

The *Saxify* model allows for additional or alternative variables at any time, the only criterion being that they be measured at specific points and aligned on a common time basis. It is neither necessary, nor practicable, to capture every feature of a musical performance in order to make comparisons with other performances, but an early decision is needed on the level of granularity of measurements. Ordinarily, these may be at a beat level but some music, such as Baroque, may characteristically have substantial runs of sub-divisions of a beat. The granular level for taking measurements needs to be chosen for each musical work, or section thereof.

The overall strategy of *Saxify* is to achieve a compression of the original data by dropping some information. It will be argued presently that this is an important choice because, paradoxical as it may sound, it can improve the efficiency and effectiveness of the model. An example of an additional performance variable could be *articulation*. This might be defined as a discrete binary (e.g. *legato* versus *staccato*) or ternary (*slurred legato*, *legato*, *staccato*) variable. Yet since articulation may be defined as the ratio of tone duration to inter-onset interval, it should be possible to provide a more precise and continuous measurement to encompass other types of articulation and other instrumental needs.<sup>10</sup>

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<sup>10</sup> Anders Friberg and Giovanni Battel, 'Structural Communication', in *The Science and Psychology of Music Performance: Creative Strategies for Teaching and Learning*, ed. by Richard Parncutt and G McPherson (New York: Oxford University Press, 2002), 206.

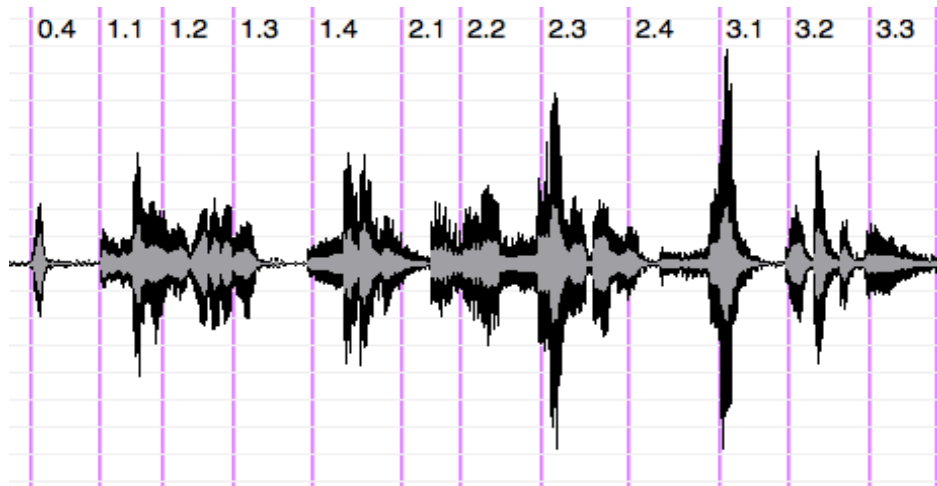
The steps in the applying the model may be summarized as follows (detailed explanations for each step are provided later in this chapter):

- Hypothesis: formulate a null hypothesis  $H_0$  (usually suggesting there is no difference or no change) or possibly a set of null hypotheses to be tested independently;
- Data Extraction, Transformation and Loading (ETL): measurements are to be made for each performance variable, at pre-specified intervals that will be common to the performances being analysed. A common problem, in time-series analysis, is misalignment of series. *Saxify* eliminates this problem by aligning all measured values on beat boundaries. This means measurements are taken at each bar/beat combination for all performances. The raw acoustic data, from both analogue and digital sources, needs to be transformed to a common base and loaded into a repository for analysis. Tempo and raw dynamic levels are measured across standard intervals. The *Phantasy* contains many runs of small-value notes with frequent time-signature changes which were found to confuse automated beat-identification software.<sup>11</sup> The most consistently effective technique for measurement was found to be a Participant-Observer approach. This involves identifying beat timings by repeat listening and then overlaying a tap track on the recordings. Performance variables may subsequently be calculated at each beat. Figure 4.1 shows an example of tapped onset timing values, which may be used to determine tempo at each beat but accepting that there are degrees of ambiguity as to sound onset, sustain and decay. The values at the top of Figure 4.1 indicate bar numbers and beats, separated from each other by a decimal point.

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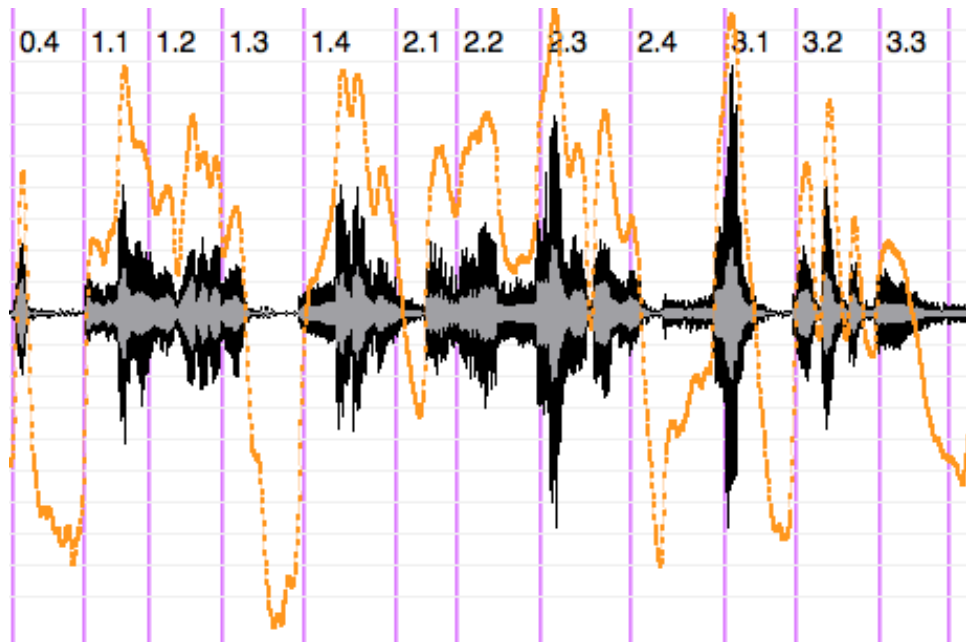
<sup>11</sup> Simon Dixon, *BeatRoot Vamp Plugin: Interactive Beat Tracking and Visualisation System*, 2011 <http://www.eecs.qmul.ac.uk/~simond/beatroot/>, Accessed 15 June 2014.





*Fig. 4.1 Example of Beat Timings*

Dynamics, measured in dBspl,<sup>12</sup> need to be extracted for each timing point and processed to produce normalized dBspl values within the 0-100 dB range.<sup>13</sup> An example is shown in Figure 4.2: the orange-coloured series shows raw dynamic levels measured at each beat interval. These raw values were then normalized to a 0-100 dB reference scale.



*Fig. 4.2 Raw dynamic levels*

<sup>12</sup> dBspl (decibels, sound pressure level) is a logarithmic measurement of the effective pressure of a sound relative to a reference value. The commonly accepted reference value is the threshold of human hearing (20microPascals) which is approximately equivalent to the sound of a flying mosquito at an average distance of 3 metres from the human ear.

<sup>13</sup> Craig Sapp, Dyn-a-Matic, <http://www.mazurka.org.uk/software/online/dynamatic/>, Accessed: 24 January 2013.

- Normalize: each data series is adjusted both for its spread and for its scale (an example of this calculation is shown in §4.13.3 below). This prevents data series that are nominally large in value from overwhelming data series that are nominally small.
- Assemble a Performance Matrix (PM): this may be mentally conceived as a spreadsheet. Each column in the PM represents the normalized values for a single performance variable. Each row represents the values at some time instant.
- Piecewise aggregate approximation (PAA): this reduces the dimensionality of each variable by quantizing a specific number of individual values into fixed-size frames. This is an important step that must take place because it: (a) requires low compute power, and (b) enables the later *performance fingerprint* dissimilarity step to operate on a subset of available data.
- Symbolic aggregate approximation (SAX): this requires the music data to be constrained into a Normal (*Gaussian*) representation; the PAA values are converted to a symbolic alphabet. It is significantly important to perform the prior PAA step in advance of the SAX step in order to achieve the benefits of data compression of the music data. The aim is to work the later stages of the model with significantly reduced volumes of data, converted to a symbolic form, while making statistically valid statements.
- Calculate a Performance Norm (PN): a PN represents an *average performance* for all the performances being analysed. It is *virtual* since it is not an actual performance and does not exist. Its purpose is to form a basis on which to judge other performance dissimilarities. It possesses the identical structure to each individual PM in that it uses the same variables and measurement points as each *real* performance. §4.11 discusses in detail how the PN may be created.
- Prepare a dissimilarity matrix (DM): a rectangular table is prepared that shows the measure of dissimilarity between all pairs of performances (including the PN).
- Discuss conclusions: based on (dis)similarities and trends.

- Cluster and visualize: data may be clustered, rather like galaxies of related stars in space, using several techniques such as Hierarchical Clustering.<sup>14</sup> However, since *Saxify* produces DMs for multi-dimensional performance data, it is important to choose an appropriate clustering method that can use the DM information.

The above combination of steps summarizes the *Saxify* model, whether of complete performances or some structural segmentations thereof, recognising that any measure of inter-performance dissimilarity will have a degree of uncertainty attached to it. Such uncertainty may be due to measurement errors that arise from the participant-observer nature of some of the music data collection work, such as creating the tapped beat-timing track. It may be due to random error arising from noisy signals. Additionally, systemic model error may be due to flaws in the logic or in how the model is applied. One important aim of an experimental design is reduction in the impact of model error.

An underlying proposition is that tempo, acceleration, loudness and rate of change of loudness are important aspects of expressive delivery. The model is designed to capture at least those aspects that provide a consistent means of expressing dissimilarities, and also, to be extended later with additional performance variables.

### 4.3 Data

A working assumption is that an individual musical performance may be represented by an intensity map that represents the ebb and flow of specific combinations of performance variables over time, even if we can neither identify all possible variables nor their relative importance. Music is continuous sound whereas an empirical model must rely (for most variables) on measurements taken at discrete time intervals. Table 4.1 shows an extract from the PM (from the downbeat on bar 2, marked 2.1 to that of bar 4, marked 4.1) from a 1951 recording of the *Phantasy*, by Koldofsky and Steuermann. It should be noted that the tempo at the first downbeat in bar 2 was measured at 41.86 beats per minute, which is much slower than Schoenberg's indicated *Grave* 52 crotchet beats per minute. It is also notable that Koldofsky maintains a

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<sup>14</sup> Alberto Fernandez and Sergio Gomez, 'Solving Non-Uniqueness in Agglomerative Hierarchical Clustering Using Multidendrograms', *Journal of Classification*, 25 (2008), 43.

relatively constant tempo at each beat, neither accelerating nor decelerating significantly (BPS/S).

Sec	Bar/ Beat	BPM	BPS	BPS/S	dB <sub>spl</sub>	dBDelta
10.61	2.1	41.86	1.43	0.06	68.20	2.82
12.12	2.2	39.80	1.51	-0.05	75.00	3.14
13.42	2.3	46.22	1.30	0.00	77.00	0.71
14.94	2.4	39.45	1.52	0.06	77.00	0.07
16.43	3.1	40.21	1.49	-0.15	77.20	0.08
17.57	3.2	52.87	1.13	-0.09	77.20	-1.32
18.85	3.3	46.70	1.28	-0.02	74.00	-6.69
19.94	3.4	55.01	1.09	-0.26	61.30	1.80
20.74	4.1	75.65	0.79	0.28	77.40	-2.47

*Table 4.1 Performance Matrix Extract (Koldosky-Steuerma51)*

Each reference is for a specific Bar/Beat (second column) whose absolute onset time (seconds from beginning) is shown in the leftmost column. Measured tempo, in beats per minute, is in the third column (BPM). Tempo, in beats per second, is shown in the fourth column (BPS) and calculated as BPM/60. Point acceleration rate is shown in the fifth column (BPS/S) with negative values indicating deceleration. Normalized sound pressure level is shown in the sixth column (dB<sub>spl</sub>). Point rate of change of dynamics with respect to time is shown in the seventh column (dBDelta) with negative values indicating a rate decrease.



*Ex. 4.3 Bars 3 and 4*

Ex. 4.3 shows the score extract represented by the measurements shown in Table 4.1. The opening motifs and the complete row have been stated by the end of bar 3. Overall, and driven chiefly by the piano, the playing tempo is 1.09 beats per second at the last beat of bar 3, before decreasing again, while the overall sound level drops to 61.3 decibels and rises on the violin upbow in bar 4. At this point Koldofsky is just

beginning to increase the dynamic drop-off rate (from 1.8 dbDelta to -2.4 dbDelta), as he aims for the  $p$  marking on the second beat of bar 4.

#### 4.4 Sources

The Discography identifies all of the recordings used for this dissertation. Sources of online material, YouTube in particular, are now proving extremely significant to music researchers since rare, or otherwise unobtainable, recordings are often made readily available there. However, there is an authenticity limitation in that many recordings available online, or streamed online, cannot be guaranteed to be the performers claimed in the credits. In instances of uncertainty, the choice was made to purchase or otherwise acquire authenticated recordings for research purposes. There is always a possibility of encountering another *Hatto* fraud controversy.<sup>15</sup> The performance model, as defined in this dissertation, is sufficiently robust to detect if one recording is masquerading as another. It is straightforward to determine if the DM for one performance is statistically different from another.

#### 4.5 Experiments

The experimental approach must be rigorous, extensible, scalable and repeatable. Rigour, meaning clear assumptions and process steps, is a requirement of analysis, whether quantitative or qualitative. It also assures that all relevant music data are captured and that only relevant data are targeted. Extensibility is necessary, since the model needs to be able to cope with adding different, possibly as yet unknown, types of music performance data. The model has two important characteristics: (1) Scalability—it is not limited to short or simple musical extracts; (2) Repeatability—other researchers can replicate its results and repeated application on one performance will arrive at near-identical results. It is hoped that this model will be useful to emergent innovations in music research including, but not limited to, new composing techniques, instrument design, MIR and computational models of music perception.

#### 4.6 Performance style

Since the overarching goal of this research is to detect changes in expressive performing style over the half-century commencing 1951 to 2013, it is necessary to discuss the

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<sup>15</sup> See Chapter 6, §2

meaning of performing style and how the model will set about detecting it. In the search to explicitly detect expressive styling and compare performances, the model must be capable of handling a variety of characteristics such as tempo, phrasing/shaping, pitch and loudness, as well as instrument-specific characteristics (even beyond piano and violin) that include vibrato, pedalling, tonguing and fingering. Encompassing the totality of such characteristics in an analytical model is a worthy goal, even if it is difficult to agree how variables of performance intensity might operate in circumstances where listeners' feelings were unclear, at least on early experiences of unfamiliar music.

Typical expressive gestures that might otherwise make sense in the context of tonal music may be judged differently when considering non-tonal music, not least Schoenberg's twelve-tone compositions. Such gestures may appear irrelevant or even inappropriate to many listeners who may be confused by the apparent non-existence of any specific key. Schoenberg preferred the term *pantonality*, comprising all keys. He did not set out to obliterate key but to treat the twelve tones as equally important. His re-orderings of the row were systematic, developed as part of his overall theories of variation and derived from the nineteenth-century idea of 'motive as the generator of larger formal structures', something with which Schoenberg was very familiar in the music of Wagner and Mahler.<sup>16</sup> Babbitt can be seen to support the view that the tone row is 'far more importantly viewed as an ordering than ... ultimate chromaticism'.<sup>17</sup> Voice-leading, for Schoenberg, operated within the context of his ideals of harmonic progression.

Most (successful) performers adhere to the macro elements of a score, at least where a composer's intentions are both known and unambiguous. Widmer and Goebbl note the evidence for strong similarities between performances of Schumann's *Träumerei*<sup>18</sup>:

pianists more or less observed the major ritardandi in the piece and clearly expressed the large-scale phrase structure of the piece through their timing – the differences between the pianists increased at lower levels of the structural hierarchy. A statistical analysis revealed a number of characteristic and distinctive phrasing behaviours, some of which could be associated (in a statistical sense) with certain pianists.<sup>19</sup>

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<sup>16</sup> Norton Dudeque, *Music Theory and Analysis in the Writings of Arnold Schoenberg (1874-1951)* (Aldershot: Ashgate Publishing, 2005), 13.

<sup>17</sup> Milton Babbitt, 'My Vienna Triangle', in *Collected Essays of Milton Babbitt*, ed. by Stephen Peles and others (Princeton NJ: Princeton University Press, 2003), 475.

<sup>18</sup> *Träumerei* is from Robert Schumann's *Kinderszenen*, Op. 7.

<sup>19</sup> Widmer and Goebbl, *Ibid.*, 210.

The same authors note a previous conference paper by Goebbl *et al.* that used performances of Chopin by several pianists to reveal individual, yet characteristic ‘performance strategies’.<sup>20</sup>

In attempting to detect differences in interpretations, a model must be capable of looking at the totality of each performance but provide detailed information at any arbitrarily lower level. Musical performance style is an aggregation of the characteristics of performance: not so much individual performances but a class of performances that may belong to a period in time, to a socio-cultural framework, a performing *school*, or even a single performer. In totality, a performance style might include relationship to an audience and its involvement, whether music is scored, improvisation, whether the musicians belong to an elite social grouping, specific dress conventions, or whether music is performed for a specific ritual. The *Saxify* model provides for characteristics that can be measured and, if necessary, interpolated, ranked and compared. The present research is not concerned with non-aural aspects of performance and makes no attempt to incorporate this in the model.

It is worthwhile to consider some new variable being added to the model. Keyboard articulation may appear to be a straightforward *legato versus staccato* concept. Experienced players know there may be a huge range of ways to actually articulate a note on a piano in a nuanced way. It is conceptually possible to define a range of values, for example, the 1-10 range of integers, that represent a spectrum ranging from fully *legato* at one end to highly-emphasized *staccato* at the other. In this way, every note (or beat) of a performance could have an attached *articulation score* that acts as a measurement of a performance value, just as Ornoy listened intently to many recordings of Bach’s G minor Adagio for Solo Violin in an attempt to classify players on a range of such characteristics.<sup>21</sup> He concluded that the younger Galamian/American school of violinists made significantly more varied use of articulation. The benefit of a computer-assisted approach is to take more of the data-collection burden at the front end and, by

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<sup>20</sup> Widmer and Goebbl, *Ibid.*, 211. See also Werner Goebbl, Elias Pampalk, and Gerhard Widmer, ‘Exploring Expressive Performance Trajectories: Six Famous Pianists Play Six Chopin Pieces’, in *Proceedings of the 8th International Conference on Music Perception and Cognition (ICMPC’04)*, (presented at the 8th International Conference on Music Perception and Cognition (ICMPC’04), Evanston, Illinois, 2004).

<sup>21</sup> Ornoy, *Ibid.*, 36.

providing highly-detailed information on what is going on in a performance, facilitate MPS researchers to apply consistent analysis.

#### 4.7 Goals and initial discussion

In respect of historic performances on record, raw data must be captured directly from recording media. MIDI recordings offer the greatest detail of performance data but are rarely available.

A performance comprises a multivariate time-series of *intensity contours* (IC). Each univariate series (column of values) within the time-series is a musical variable measured at selected time instants. A time-series is a particular data-type that may be involved in at least two types of related enquiry. The first is *search*, where a specific time-series (for present purposes, a performance) is sought within a corpus of performances. This can be termed *data mining*. The second is *(dis)similarity*, where the nature of the enquiry is about how (dis)similar are two series. In order to avoid time-warping effects, where variables to be measured at differing intervals, all performances are transformed from a time-based series to a musical *beat within bar*-based one. It is important to have the guarantee that all the univariate series that make up the *performance matrix* are aligned in time. This facilitates comparison of the bundle of variable values taken from different performances.

*Saxify* operates to four goals in delivering a useful measure of music performance dissimilarity. It aims to minimise the time spent on carrying out calculations and evaluation, be meaningful to musicians and music researchers, consistently give the same results if a test is repeated, and relate performances, as being more or less similar, in a testable form.

#### 4.8 Selecting time-based variables to measure

In evaluating expressive delivery, the initial task is to choose representative characteristics that can each be measured consistently and completely for a set of performances. There must be no measurement problem arising from varying time-signatures, even as exhibited, sometimes on a bar-to-bar basis, in Schoenberg's *Phantasy*.



It has already been noted that many studies of expressivity have incorporated measurements of tempo and dynamics. In addition to their raw values, there are more subtle aspects as to how tempo and dynamics are managed by a performer. It may take a certain amount of time to get from point A to point B, but there are many possible variations in speed along the way. One performer may play at a very constant pace; another may vary the rate of acceleration at times. Another may increase the pace a little at first and then a lot. This also applies to changes in dynamics. The conventional hairpin indicators of *crescendo/decrescendo* provide no guidance as to how the loudness increase/decrease is to proceed. Recordings demonstrate a great degree of variability in these rates of change, both at different points in a score and for different performers. It should be understood that no specific aspect of the model depends upon which variables are chosen, although the results may differ.

#### 4.9 Extending the model

A fundamental objective of the model is to enable additional performance variables to be added without changing the underlying logic. The software controls where the data files reside, how many variables to process, and, any weightings to be applied to variables, where they can be justified musically. Adding variables increases dimensionality and numerosity, which may lead to false correlations. It is very difficult to visualize high-dimension data.

#### 4.10 Time instants and base tempo

The chosen performance characteristics must be measured at each such instant. The granularity of measurement is both high enough to balance ease of identification and low enough to provide useful data.

The *feature vector* of discrete values, one per variable specified at a time-instant  $t$  (accepting that music is a continuous auditory phenomenon) is an *intensity contour*,  $IC_t$ . In order to facilitate identification, we might label time instants with bar number and beat. So, for example,  $T_{5:1}$  is the Tempo measured at beat 1 of bar 5. This identification approach has two advantages: it provides for instant association of the value  $t$  with a specific location in the score irrespective of varying time-signatures. An intensity contour,  $IC_t$ , for two performance variables might be defined as follows where  $A$  is the acceleration rate at time  $t$ :

$$IC_t = \{A_t, D_t\}$$

Fig. 4.4 Sample Intensity Contour (1)

This is the instantaneous rate of change of tempo: in mathematical terms this is the slope of a tempo curve at the measured point (it may have positive or negative values: positive meaning the rate of acceleration and negative meaning the rate of deceleration).  $D$  is the rate of change of dynamic level at time  $t$ . This is the instantaneous rate of change of loudness intensity (defined as  $dB_{spl}$  and constrained to be within a range 0-100).<sup>22</sup>

It is proposed that expressivity be represented by changes in ICs, as a performance proceeds - a multivariate map flowing in the time dimension. In principle, there is an infinite number of time-instants at which measurements might be taken. For large music datasets, it is possible to rely on the Central Limit Theorem to infer statistical significance of results.<sup>23</sup>

A useful extension of *Saxify* would be to treat a subset of recorded performances as a training set, in the sense of training a *machine learning* algorithm.<sup>24</sup> Assuming the performance style parameters were consistent, it might then be possible to classify where additional, unknown, recordings lie on a timeline, or to retrieve performances that appeared to exhibit time-related characteristics. Although this PM is here restricted to taking measurements at time instants of acceleration and rate of change of dynamics, a typical  $IC_t$  might be extended with many more variables, for example, where  $T$  is Tempo (measured in Beats per Minute),  $F$  is Absolute Pitch (frequency), or more likely a basket of frequencies comprising the fundamental and some number of harmonic overtones,  $VD$  is Vibrato depth (e.g. cents, being percentages of a semitone),  $VF$  is Vibrato frequency (cycles per second measured in Hertz), and  $D$  is melody lead (measured in mS) either between the hands of a pianist, or between two, or more, instruments:

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<sup>22</sup> Each 20-unit increase in  $dB_{spl}$ , being logarithmic, represents 10 times the loudness of the lower value. By way of comparison, a trumpet at 0.5m may typically be measured at  $dB_{spl} = 130$ . It is noteworthy that there is an instantaneous risk of permanent hearing loss for a loudness measurement at the ear of  $dB_{spl} = 120$ .

<sup>23</sup> Hans Fischer, *A History of the Central Limit Theorem* (New York: Springer, 2011); and see Eric Weisstein, 'Central Limit Theorem' <http://mathworld.wolfram.com/CentralLimitTheorem.html>, Accessed: 13 August 2013.

<sup>24</sup> John Kelleher, Brian MacNamee and Aoife D'Arcy, *Fundamentals of Machine Learning for Predictive Data Analytics: Algorithms, Worked Examples and Case Studies*, 1st edn (Boston: MIT Press, 2015).

$$IC_t = \{T_t, F_t, VD_t, VF_t, D_t\}$$

Fig. 4.5 Sample Intensity Contour (2)

Audio processing software, such as *Sonic Visualiser* and *Audacity*, can greatly improve the efficiency of processing audio data. This includes overlaying an audiogram (a graphic visualisation of an audio stream) with characteristic graphs. One example, in the time domain, is dynamic level which may be automatically mapped to beats. There is a large range of plugins, researched at both academic and commercial institutions, that can process audio signals. By using such software, a researcher may record and then re-work a *tap track* to map very accurately a time-varying performance tempo and anchor the times at which events will be located.

Several automated techniques exist to calculate beat onset. Such techniques were researched but were found to be generally inadequate in dealing with polyphonic voices, dense musical figuration, or varying time signatures.<sup>25</sup> The most effective technique was found to be tapping the beat onsets by hand and then using automated tools to adjust data points as close as possible to their onset. Thus, the accuracy of note onset measurements may be optimised by filtering them through *Tapsnap* which attempts to move tapped beats to the nearest identified onsets in the audio recording.<sup>26</sup> The output from this program may then be re-checked by ear for accuracy and re-adjusted as necessary. *Tapsnap* takes, as input data, a text file with event timings, such as measurement of tempo at each beat.

There are significant problems in comparing the dynamics of musical performances in absolute terms. Dynamic level is a function of the physical medium in which the sound is created, the mechanical technique of sound production by the performer, psychoacoustic perception by the listener—each listener may perceive loudness differently, widely varying playback technologies, and physical characteristics of the

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<sup>25</sup> See VAMP audio plugins developed among others by researchers at the Centre for Digital Music, Queen Mary, University of London (partially funded by the EPSRC through the OMRAS2 project EP/E017614/1, and partially funded by the European Commission through SIMAC project IST-FP6-507142 and the EASAIER project IST-FP6-033902). There are also plugins developed at the BBC, University of Alicante, and by many others listed at <https://www.vamp-plugins.org/download.html>

<sup>26</sup> Craig Sapp, *Tapsnap*, <http://mazurka.org.uk/cgi-bin/tapsnap>, Accessed: 24 November 2013.

space (generating *reverberation*)—dispersion characteristics of sound may impact on perceived loudness.

#### 4.11 Acceleration rates of tempo and loudness

Subtle expressive effects may lie unseen in momentary acceleration/decelerations.

These represent, in mathematical terms, the first derivative of velocity with respect to time or, in geometrical terms, the slope of a tangent to the tempo curve at a point. The rate at which a player is continually speeding up and slowing down may be measured in *beats per second per second (BPS/S)*. Since the tempo curve obtained from a musical performance cannot be expressed by a single, simple mathematical function, there is no consistent way of differentiating a function to obtain tangent slopes. The slope of a curve at a point represents the rate at which the Y-axis is increasing/decreasing with respect to time. So, if the curve is a tempo curve, the point slopes represent momentary acceleration/decelerations. If the curve is a loudness curve, the slope is the point rate of increase/decrease in loudness. By this means it is possible to obtain a vector of measurements of acceleration/deceleration at each beat interval and use this as a variable of the PF.

Figure 4.6 below is one way to approximate the slope of a curve (of which negative values mean deceleration) at a point (defined as having co-ordinates  $X_2, Y_2$ ) relative to the two theoretically closest points on either side of it (having co-ordinates  $X_3, Y_3$  and  $X_1, Y_1$ ). It may be estimated by:

$$\frac{(Y_3 - Y_1)}{(X_3 - X_1)}$$

Fig. 4.6 Acceleration/deceleration at an arbitrary point ( $X_2, Y_2$ )

where  $Y_n$  is a measured value at instant  $n$  and  $X_n$  is the number of seconds elapsed since the start of performance, measured at instant  $n$ . Beat-to-beat error should balance out when slopes are calculated for many data points (some will be high and some low). It may be argued that a tempo curve based on beat intervals does not possess sufficient granularity to calculate slope precisely. This is not a serious limitation since the curve may be recalculated at any arbitrarily level of time granularity. Downsides of doing the latter, instead of at a crotchet or dotted crotchet beat, may include: having to perform many more calculations, or considering whether a musician could consciously influence acceleration rates over tiny time intervals. It seems likely that tiny random variation in

motor processes would swamp the positive intent of any conscious mind, even accepting that skilled musicians exhibit exceptionally ‘high levels of conscious motor control’.<sup>27</sup>

Sound intensity is the energy dissipated by a sound wave and is defined in *watts per unit area*. Saying that two sounds have equal intensity is not the same as saying that they have equal loudness. Humans perceive the *intensity* of sound as *loudness*. Hearing sensitivity varies with frequency. It can be useful to plot equal loudness curves to show variations for a human ear.<sup>28</sup> Two different sounds, each at 60dB sound pressure level, may not be said to have the same loudness unless they are playing the same frequency. In considering loudness of recordings, the listener must be aware that the most prominent sound is often not the one with the highest dynamic level and that loudness estimates can be wrongly estimated by distance cues, timbre, performance intensity, density of instrumentation, pitch-register or any information that modifies a listener’s focus.<sup>29</sup> Trained singers are capable of modifying the harmonic composition of a pitch, specifically for vowel sounds, to ensure that their voice can soar above an orchestra without necessarily singing louder (the singer’s *formant*) but by generating more energy at specific frequencies.<sup>30</sup>

In ensemble performance, the question arises as to whether an individual instrument, or some aggregate of instruments may be measured for all performance variables. Measuring the dynamics of a violin part in a duo is difficult against the backdrop of a complex piano part. Given the variation in recordings and playback equipment and an unknowable amount of sound engineering, levelling or balancing during production phases, I decided to focus on the more significant violin part for tempo acceleration measurements and on the overall dynamic level of the duo for loudness acceleration measurements.

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<sup>27</sup> Andreas Lehmann, ‘The Acquisition of Expertise in Music: Efficiency of Deliberate Practice as a Moderating Variable in Accounting for Sub-Expert Performance’, ed. by Irene Deliege and John Sloboda (Hove: Psychology Press, 1997), 154.

<sup>28</sup> Stanley Gelfand, *Hearing: An Introduction to Psychological and Physiological Acoustics*, 5th edn (London: Informa, 2010), 208.

<sup>29</sup> William Moylan, *Understanding and Crafting the Mix: The Art of Recording* (Oxford: Focal Press, 2007).

<sup>30</sup> Sang-Hyuk Lee and others, ‘The Singer’s Formant and Speaker’s Ring Resonance: A Long-Term Average Spectrum Analysis’, *Clinical and Experimental Otorhinolaryngology*, 1.2 (2008), 92.

Several available recordings may have originated as monophonic sources or masters. Even on a stereo recording, it is generally impossible to separate 100% of each instrument's audio signal, due to cross-channel signal bleed, which may often be accidental but is more likely a result of purposeful sound engineering. Extracting one part alone becomes very dependent on the musical skills of the researcher. When and if tools are developed that can separate instruments easily and unambiguously, the *Saxify* model will be able to use the data values arising.

My research programme adopted the *PowerCurve::Smoothed Power* plugin, implemented for Sonic Visualizer, to process sound pressure levels.<sup>31</sup> This normalises loudness values in the range 0 to 100, at each beat timing point, being approximately equivalent to dB<sub>SPL</sub> values. Lofft describes a related experiment where sound levels were measured at a violin and piano recital by a young virtuoso violinist, Yuri Cho, and accompanist, Michael Tan, at Merkin Concert Hall, a small 300-seat venue in New York.<sup>32</sup> Tan was playing a Steinway concert grand piano. Cho stood five feet in front of the piano. At fifteen feet from a RadioShack meter, quieter sound levels averaged about 70 dB; when they both played loudly (*forte*), measurements peaked at 89 dB. An alternative scale, that I rely on for this dissertation, published at the Mazurka plugin page from CHARM, proposes that a difference in dynamic values of 10 dB<sub>SPL</sub> may be assumed as approximately equal to one level change in musical dynamics.<sup>33</sup> For example, if the dynamic *piano* is assigned to the numeric value 50, *mezzo-piano* would be at 60; *mezzo-forte* 70; *forte* 80; etc. The output data from the plugin contain smoothed measurements of amplitude in decibels, calculated every 10 milliseconds in an audio file. The *PowerCurve::Smoothed Power* algorithm provides a slight inbuilt delay to compensate for the likelihood that the maximum loudness of a note will follow its onset. Lower suggested values than measured at the live concert may be explained by

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<sup>31</sup> Craig Sapp, *PowerCurve Plugin for SonicVisualiser (header Source Code)* (The Mazurka Project, 2006), <http://www.mazurka.org.uk/software/sv/plugin/MzPowerCurve/src/MzPowerCurve.h.html>, Accessed: 14 January 2014. Note that the double colons in *PowerCurve::SmoothedPower* are necessary in order to refer to a function within a C++ programming language library, which is the standard development language for such plugins. The online version of the Dyn-A-Matic plugin, developed at the CHARM project, is provided at <http://www.mazurka.org.uk/software/online/dynatic/>. Accessed 14 January 2014 - the mapping of dynamic markings to approximate dB<sub>SPL</sub> levels is discussed in detail on that webpage.

<sup>32</sup> Alan Lofft, 'The Decibel (dB) and the Violin/Piano Recital', *Audioholics: Online A/V Magazine*, 1 October 2008 <https://www.audioholics.com/editorials/the-decibel-db>. Accessed: 14 May 2018.

<sup>33</sup> The online version of the plugin, developed at the CHARM project, is provided at <http://www.mazurka.org.uk/software/online/dynatic/>, Accessed 14 January 2014 - the mapping of dynamic markings to approximate dB<sub>SPL</sub> levels is discussed in detail on that webpage.

a combination of normalisation into the 0-100 dB<sub>spl</sub> range, and the performing characteristics of the performance space.

#### 4.12 Recording lead-in/-out

Music recordings may obscure starting or ending notes on a recording. This is particularly the case with older recordings, and with those made in a live setting with clapping and/or audience noise. For this reason, initial beats (and final beats) of each performance should be eliminated from like-for-like comparison.

#### 4.13 *Saxify* procedure

An important aspect of *Saxify* is the development of a PN against which to reference recordings. This facilitates an argument about trends in performance over time. The PN can only be developed after processing data from individual recordings and is discussed in §4.13.5 below.

Steps of the *Saxify* procedure shall now be described in detail. Recordings are represented by quantized numeric values of the selected variables at beat points.<sup>34</sup> Quantization, in this model, means allocating ranges of X values to specific Y points (in this case the nearest value is always chosen, but alternatively it may be the next highest or next lowest). This is similar to the quantization technique used in creating digital recordings such as CD or DVD. This process converts the ‘almost infinitely variable amplitude of an analogue waveform to one of a finite series of discrete levels’.<sup>35</sup> The particular type of quantization performed (for example average, nearest highest, nearest lowest) may explain why some listeners claim that non-digital recordings are higher fidelity.

All music performance data was stored on an Excel spreadsheet with one performance per tab.<sup>36</sup> The PN is stored on a separate tab, with formulae that automatically calculate the correct values for average tempo, average loudness and the rates of change. For datasets derived from longer, larger, or more complex performances, a typical open-

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<sup>34</sup> Initial code experiments were developed in Java and extended Senin’s work - Pavel Senin, *Jmotif: Time Series Data Mining Toolkit Based on SAX and TFIDF Statistics*. <https://code.google.com/p/jmotif/downloads/list>, Accessed: 13 April 2013. Ultimately the entire Saxify code was re-developed in the R statistical programming language.

<sup>35</sup> See the Audio Engineering Society’s Pro Audio Reference at <http://www.aes.org/par/q/>

<sup>36</sup> Microsoft Excel for Mac 2011 Version 14.7.7

source database such as MySQL, or SQLite embedded on a mobile device, could be considered more appropriate for data storage.<sup>37</sup>

It was decided that the data to be recorded for each performance should be measured at the sequential time-instants at which each bar/beat occurs. The granularity of time-instants must balance ease of identification with usefulness of the data. Performance characteristics at each specific time-instant, being a *slice* across all variables, collectively form an *intensity contour* (IC). It is proposed that expressivity can be represented by the changes in ICs, as the performance proceeds: a multivariate map flowing in time.

It is useful in any multivariate times-series analysis to show that the variables are not correlated, which could weaken the logic of a weighted aggregation of variables. A simple way of achieving this is to calculate Pearson Correlation Coefficients (PCC) for each pair of variables. Low values of PCC indicate low dependencies between variables. It was also decided to calculate the probabilities that low PCCs were randomly derived and so could not be relied upon.

There are significant problems in establishing the distance (dissimilarity) between multivariate time series. This is compounded by the issue of dimensionality: it is relatively easy to comprehend dissimilarity in one or two dimensions. However, once we move to higher dimensions there are insuperable challenges to the human mind. The approach taken in the present research is to create a weighted univariate series from the combined dimensions of the normalised music data. In the steps outlined below, this can be seen at 4.13.5.

#### **4.13.1 Extract, transform, load**

Recordings might be acquired from several sources including, but not limited to: (1) vinyl records, (2) CD/DVD, (3) *FLAC* (free lossless audio codec) formats, (4) digital downloads from online stores such as iTunes, (5) digital downloads (e.g. from the Schoenberg Centre Archive), and (6) as free digital downloads from YouTube.<sup>38</sup> It was found convenient to refer to each recording with the

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<sup>37</sup>Axmark, David, Widenius, Michael. (2015). *MySQL 5.7 reference manual*. Redwood Shores, CA: Oracle.

<sup>38</sup> See archive at [www.schoenberg.at](http://www.schoenberg.at) and at Arnold Schönberg Center, Schwarzenbergplatz 6, Eingang Zaunergasse 1-3, A-1030 Wien (I visited the Arnold Schönberg Center in September 2013).



general template: ‘violinist-pianistYY’ where each of the musicians is referenced by surname followed by the recording year, e.g. Varga-Krenek51. In certain cases, there were found to be either ambiguities or no reliable data regarding the original recording date. Best estimates, such as a release date, was used in such cases. The sequence of processing recordings should ideally be randomised in order to minimise systematic bias arising from changes in manual tapping accuracy. Each recording must be transferred from source to a common computer-readable format, using a software tool such as the freely available *Audacity*.<sup>39</sup> Vinyl recordings may be transferred using a record deck that can be connected directly to a computer running *Audacity*. It is recommended to standardize all recordings to now patents-free MP3, or to open-source format such as *Ogg* unless sound fidelity causes particular problems for the measurement of some variables.<sup>40</sup>

#### 4.13.2 Generate timing information

Beat timing data for each performance must be extracted from *Sonic Visualiser* and stored in the prepared Excel worksheet or some suitable database.<sup>41</sup> Dodson recommends, for analysis of tempo variation, that a three-step process (tapping, automated onset detection with alignment, and manual correction) is an efficient and accurate procedure.<sup>42</sup> There may be some bias that causes tapped timings to lag or lead the true values. Across a substantial body of recordings this bias is assumed to average out against ground truth.

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<sup>39</sup> Audacity Team, <http://audacity.sourceforge.net/>, Accessed: 20 January 2012.

<sup>40</sup> Ogg is a common multimedia file format standard that is maintained by Xiph.org. European mp3 patents expired 2012 and USA patents 2017.

<sup>41</sup> Chris Cannam, Christian Landone and Mark Sandler, ‘Sonic Visualiser: An Open Source Application for Viewing, Analysing and Annotating Music Audio Files’, in *Proceedings of the ACM Multimedia 2010 International Conference* (presented at the ACM Multimedia 2010 International Conference, New York: ACM, 2010).

<sup>42</sup> Alan Dodson, ‘Solutions to the “Great Nineteenth-Century Rhythm Problem” in Horowitz’s Recording of the Theme from Schumann’s *Kreisleriana*, Op. 16, No. 2’, *Music Theory Online (MTO)*, 18.1 (2012), 2/11.

#### 4.13.3 Normalize each variable

Each music variable should be individually re-calibrated since ‘it is meaningless to compare data series with different offsets and amplitudes’.<sup>43</sup> This calibration process, termed *Normalization*, is a standard statistical procedure in multivariate analysis so that no single variable may overwhelm others purely on account of its absolute scale. There are two main methods that are usually applied to normalization: (1) Z-score normalization that recalculates each variable’s data on both its own central tendency (usually the arithmetic mean) and its spread (variance) about that centre where  $V_i$  is an individual data point,  $\mu_{V_i}$  is the mean of all the data points, and  $\sigma_{V_i}$  is the standard deviation of all the points:

$$V_i = \frac{V_i - \mu_{V_i}}{\sigma_{V_i}}$$

Fig. 4.7 Z-Score normalization

(2) Range scaling is an alternative normalization approach that recalculates each variable’s data based on its minimum and maximum values where  $V_i$  is an individual data point,  $\min(V_i)$  is the minimum of all the data points, and  $\max(V_i)$  is the maximum of all the points:

$$V_i = \frac{V_i - \min(V_i)}{\max(V_i) - \min(V_i)}$$

Fig. 4.8 Range scaling

Z-score normalisation is the method chosen for present purposes since high Z-scores can be used to indicate non-random outliers. Range scaling transforms all values into the 0-1 range and is not therefore sensitive to spotting outlier data. In the following example, sample loudness values are extracted from one of the recordings in order to demonstrate how the *normalization* step works:

1.043, -0.362, 2.482, 5.524, -1.291, 0.651, 1.241, -3.575, -6.246, -0.629

These data values are plotted as follows in Fig. 4.9:

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<sup>43</sup> Jessica Lin and Yuan Li, ‘Finding Structural Similarity in Time Series Data Using Bag-Of-Patterns Representation’, in *Proceedings of 21st International Conference on Scientific and Statistical Database Management*, ed. by Marianne Winslett (presented at the SSDBM 2009, Berlin: Springer, 2009), 464.

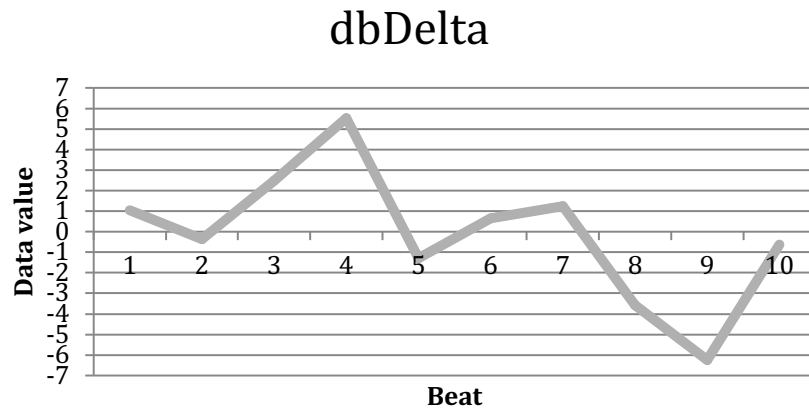


Fig. 4.9 Sample time-series plot

The simple average (arithmetic mean) of the above values is -0.12 and the standard deviation is 3.22. The normalized series is:

0.36, -0.08, 0.81, 1.75, -0.36, 0.24, 0.42, -1.07, -1.90, -0.16

These values are plotted in Fig. 4.10 and may be seen as a downward, vertical, transformation of the original series around its new mean of 0, its basic shape being perfectly preserved. *Normalization* shifts a time series towards the new mean. It would not be meaningful to compare time series with different offsets and amplitudes.<sup>44</sup>

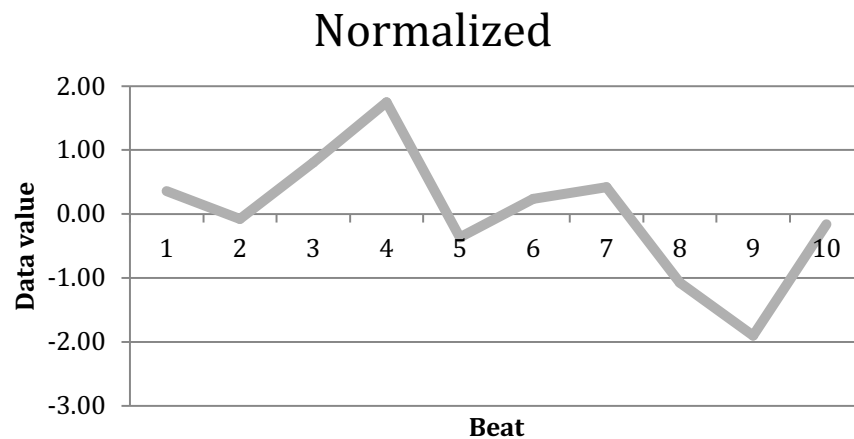


Fig. 4.10 Normalized time-series plot

<sup>44</sup> Jessica Lin, Eamonn Keogh, Li Wei and others, 'Experiencing SAX: A Novel Symbolic Representation of Time Series', *Data Mining Knowledge Discovery*, 15 (2007), 114.

#### 4.13.4 Piecewise aggregate approximations (PAA) and Symbolization

The next step is to perform PAA whereby each original time-series of is approximated by a vector of arbitrary lesser length. This requires the original time-series to be divided into equally sized frames following which an average value may be calculated for each frame. In order to reduce the dimensionality, the original time-series is firstly split into equally sized frames before computing the mean values.<sup>45</sup> The new sequence is termed the *PAA transform* of the original.

Consequently, if we define the reduced vector to be 50% of the original length (10 values) the PAA transform is:

0.14, 1.28, -0.06, -0.33, -1.03

This may be visualised as the stepped box plot, overlaid on Fig. 4.11:

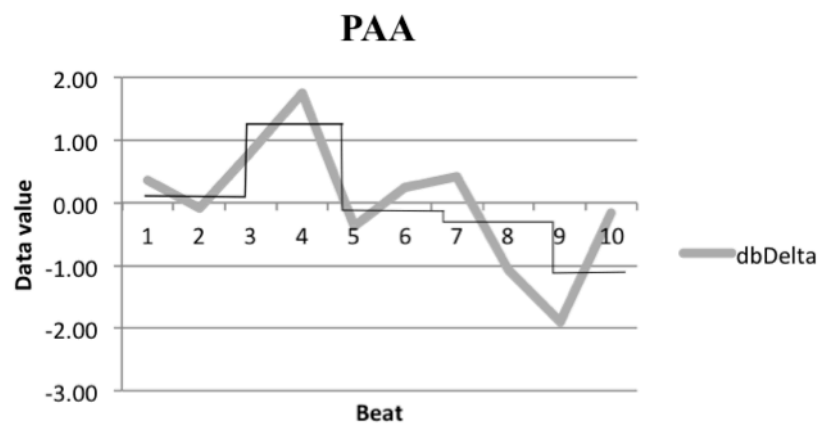


Fig. 4.11 PAA transform of sample data (Boxplot line)

Take a weighted average combination, of the values that represent each performance variable, by aggregating multiple normalised PAAs. For present purposes there is no clear advantage to be obtained from applying differential weights (although the *Saxify* software allows for them).

The original music data have now undergone two important reductions. PAA has transformed the original data of the performance to an arbitrarily reduced proportion of its dimensionality. Considerable additional experimentation is

<sup>45</sup> Eamonn Keogh and others, 'Dimensionality Reduction for Fast Similarity Search in Large Time Series Databases', *Journal of Knowledge and Information Systems*, 3 (2001), 263–86.

possible on the PAA length in relation to different types of music, but the underlying principle is unaffected by the maximum length of this symbol string. Consider this reduction as particularly important in terms of extending the model to longer musical works. Any reduction in data volume may be considerable but even large reductions may be made without compromising the logic. Individual values are weighted and combined.

Typically, for a maximum alphabet size of five discrete symbols, the PAA will be converted to a symbol string that may look somewhat like:

bcbaaddaaddbb.....

At this stage of the procedure the original music data has been converted into a number of SAX strings – one for each of the variables in the original PM and one for the variables combined.

From a mathematical viewpoint, it is ideal for distance values to be *metric*, which is a mathematical value that unambiguously satisfies four criteria covering three theoretical performances  $P_x$ ,  $P_y$  and  $P_z$ . These criteria are as follows: non-negativity (the distance between  $P_x$  and  $P_y \geq 0$ ), identity (if the distance between  $P_x$  and  $P_y$  is 0 then  $P_x \Leftrightarrow P_y$  where  $\Leftrightarrow$  means ‘is equivalent to’), symmetry (the distance between  $P_x$  and  $P_y \Leftrightarrow$  the distance between  $P_y$  and  $P_x$ ) and triangle inequality: (the distance between  $P_x$  and  $P_z \leq$  (distance from  $P_x$  to  $P_y$ ) + (distance from  $P_y$  to  $P_z$ )). Consider the case of two original time series  $Q$  and  $C$ . The minimal distance (MINDIST) between two string representations of  $Q$  and  $C$  is defined as:<sup>46</sup>

$$MINDIST(Q', C') \equiv \sqrt{\frac{n}{w}} \sqrt{\sum_{i=1}^w (dist(q'_i, c'_i))^2}$$

*Fig. 4.12 MINDIST measure of dissimilarity*

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<sup>46</sup> Jessica Lin, Eamonn Keogh, Stefano Lonardi and others, ‘A Symbolic Representation of Time Series, with Implications for Streaming Algorithms’ (presented at the 8th ACM SIGMOD Workshop on Research Issues in Data Mining and Knowledge Discovery, San Diego: ACM, 2003). A more recent paper by Butler and Kazakov suggests that the PAA step may cause the symbolic data to lose its Gaussian form under certain circumstances of positive autocorrelation. It is proposed herein to ignore this limitation. See their paper at Matthew Butler and Dimitar Kazakov, ‘Creating a Level Playing Field for All Symbols in a Discretization’, *ArXiv Preprint ArXiv:1210.5118*, 2012, 1).

In Figure 4.12 above,  $n$  is the length of the original time series,  $w$  is the number of frames (i.e. PAA segments),  $Q'$  and  $C'$  are symbolic representations of the original numeric series  $Q$  and  $C$ . Furthermore,  $q'_i$  and  $c'_i$  are successive pairs of values in the symbol strings, the *dist* function uses a Gaussian (*Normal*) lookup table for distances between point pairs, for a particular alphabet size, as contained in standard statistical tables. A Dissimilarity Matrix (DM) is a square matrix in which each cell represents the degree of dissimilarity between two performances.<sup>47</sup> The singular value for each cell  $(r, c)$  in the resultant Dissimilarity Matrix is computed as:

$$cell_{(r,c)} \equiv \begin{cases} 0, & \text{if } |r - c| \leq 1 \\ \beta_{max(r,c)-1} - \beta_{min(r,c)-1}, & \text{otherwise} \end{cases}$$

Fig. 4.13 Dissimilarity calculation

The measure specifies, in MINDIST units analogous to standard deviations of normalized symbol data, how dissimilar each performance is to each of the others, including the PN. MINDIST violates both the identity and triangle inequality conditions which means it is not a distance metric. However, that limitation does not reduce its applicability as a dissimilarity measure.<sup>48</sup>

Table 4.2 shows a small extract from a Combined DM. In this example, all performances are statistically dissimilar from the PN (which is discussed fully in §4.13.5). Kolisch's repeat recordings of 1953, 1965, 1966 (yet not the 1954, nor the second 1953 recording with Stock) are seen to be close. This reinforces the likelihood that experienced musicians can deliver similar expressive performances even years apart.

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<sup>47</sup>Avraam Tapinos and Pedro Mendes, 'A Method for Comparing Multivariate Time Series with Different Dimensions', *PLoS ONE*, 8.2 (2013), sec. Introduction, <http://dx.doi.org/doi:10.1371/journal.pone.0054201>.

<sup>48</sup> Muhammad Fuad and Pierre-Francois Marteau, 'Enhancing the Symbolic Aggregate Approximation Method Using Updated Lookup Tables', Lecture Notes in Computer Science (presented at the Knowledge-Based and Intelligent Information and Engineering Systems (KES2010, Cardiff: Springer Verlag, 2010), 6276/2010, 423–4.

	PN	Koldofsky-Steuermann51	Varga-Krenek51	Kolisch-Stock53	Kolisch-Willmann53	Kolisch-Willmann54	Bress-Reiner62	Baker-Gould64	Kolisch-Johansen65	Menuhin-Gould65	Goldberg-Webster66	Kolisch-Johansen66
PN	0.00	4.83	4.63	5.59	4.42	4.57	5.09	4.10	5.06	4.65	4.83	4.91
Koldofsky-Steuermann51	4.83	0.00	2.58	4.53	2.88	1.66	3.96	3.12	1.98	3.20	2.38	3.07
Varga-Krenek51	4.63	2.58	0.00	4.85	2.84	2.86	4.06	3.34	3.32	3.25	2.20	3.24
Kolisch-Stock53	5.59	4.53	4.85	0.00	4.06	4.17	5.12	4.83	4.92	4.61	4.67	4.17
Kolisch-Willmann53	4.42	2.88	2.84	4.06	0.00	2.65	2.98	2.21	1.81	2.80	3.37	1.84
Kolisch-Willmann54	4.57	1.66	2.86	4.17	2.65	0.00	3.97	3.30	2.44	3.33	2.15	2.89
Bress-Reiner62	5.09	3.96	4.06	5.12	2.98	3.97	0.00	3.07	3.72	3.40	4.53	2.62
Baker-Gould64	4.10	3.12	3.34	4.83	2.21	3.30	3.07	0.00	2.80	2.41	4.24	2.22
Kolisch-Johansen65	5.06	1.98	3.32	4.92	1.81	2.44	3.72	2.80	0.00	3.23	3.42	2.21
Menuhin-Gould65	4.65	3.20	3.25	4.61	2.80	3.33	3.40	2.41	3.23	0.00	3.79	2.68
Goldberg-Webster66	4.83	2.38	2.20	4.67	3.37	2.15	4.53	4.24	3.42	3.79	0.00	3.58
Kolisch-Johansen66	4.91	3.07	3.24	4.17	1.84	2.89	2.62	2.22	2.21	2.68	3.58	0.00

Table 4.2 Extract from a Combined DM

A value in the DM represents the dissimilarity of two performances from each other, identified by the row and column labels. The diagonal of such a DM must always be all-zeros since the dissimilarity between a performance and itself is zero. A DM is an example of a *triangular* matrix since must always be symmetrical across the diagonal. No attempt has been made in this dissertation to take advantage of triangularity which can offer significant advantages to computer processing as well as to data storage and memory requirements.

For the example in Table 4.2 above, the dissimilarity of the Bress-Reiner62 recording from the PN is 5.09. The dissimilarity of the Kolisch-Willmann54 recording from the PN is 4.57. Therefore, the latter 1954 recording is closer to the average than is the 1962 recording, specifically in respect of the chosen performance variables.

It will be demonstrated in Chapter 6 how *averages* of dissimilarities may be used to examine the flow of expressivity across sections of a performance. I generalise the concept of a *pooled estimator* for averaging statistical variances to the MINDIST estimator. My calculation will use the dissimilarities from the PN by squaring each Mindist value, dividing by the number of values, and taking the square root of the result. This result should be interpreted as the average dissimilarity across all performances and is particularly relevant when comparing how expressive intensity flows from one structural grouping to another, where  $Z$  is the pooled estimate,  $M_1^2$  to  $M_n^2$  are the squared Mindist

values, and  $n$  is the number of individual Mindist values. One might choose to use a denominator of  $n-1$  in the formula shown in Figure 4.14 to take account of the number of degrees of freedom, however the effect on  $Z$  is typically small.:

$$Z = \sqrt{\left( \frac{M_1^2 + M_2^2 + M_3^2 \dots + M_n^2}{n} \right)}$$

Fig. 4.14 Pooled estimate of MINDIST

It should be noted at this point in the *Saxify* procedure that there are alternative measures of string dissimilarity that might be used to create the *performance fingerprint*. One outstanding alternative is the Levenshtein (or String Edit) Distance. Future research could examine the pros and cons of applying such alternatives to problems of musical performance dissimilarity.

#### 4.13.5 Extract a *Performance Norm (PN)*

Grachten and Widmer highlight the need for ‘better models of expressive timing and tempo ... needed to serve as a performance norm’.<sup>49</sup> Having developed the Performance Matrix for all available recordings, I now describe a general procedure to create an *average performance*, a *Performance Norm (PN)* against which all available recordings might be compared. Such an average is a better discriminant between performers than a norm based on a score.

The PN must have the same variables as each individual performance being studied. If, for example, the variables measured in the recorded performances are tempo and loudness, then the PN will specify tempo and loudness at each of the same measurement points as in the actual performances. An important issue is how to calculate the average tempo and average loudness at the measurement points. The completed PN is stored as another tab on the input data worksheet, with calculations performed by Excel.

*Saxify* uses specific techniques for averaging rates, ratios, logarithms and classification variables. It is not mathematically valid, for some variable types, to apply simple arithmetic averages. In particular, the appropriate average of a

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<sup>49</sup> Maarten Grachten and Gerhard Widmer, ‘Who Is Who in the End? Recognizing Pianists by Their Final Ritardandi’, in *Proceedings of the International Society for Music Information Retrieval 2009* (International Society for Music Information Retrieval, 2009).



rate (which is itself a ratio of two scalar values) is the *harmonic mean*. In musical terms, tempo is a rate (distance played in a fixed time where distance may be denoted in beats), so the appropriate average of multiple tempi is the Harmonic Mean where  $H$  is the Harmonic Mean,  $n$  is the number of tempo values, and  $x_i$  is the  $i$ th such value:<sup>50</sup>

$$\frac{1}{H} \equiv \frac{1}{n} \sum_{i=1}^n \frac{1}{x_i}.$$

Fig. 4.15 Harmonic Mean

An example of the calculation of average tempo at a point, for one row of the PN, calculated across all performances at beat 4 of the first bar, is shown in Table 4.3 as follows:

Average seconds	Bar/Beat	BPM
		average
6.88	1.4	51.28

Table 4.3 Calculating average BPM at a measurement point

The first step is to calculate *Average seconds*, the average time where the beat occurs since the start of the performance. This is a simple arithmetic average of the equivalent onset of this bar/beat across all the performances, the bar/beat being analogous to distance travelled.

It is possible to estimate a *BPM Average* at any point since the BPM at this point for each individual performance is known. The calculations shown in Table 4.3 may be combined with the formula in Figure 4.6 to calculate acceleration rates as shown in the rightmost column (*Beats per Second per Second*) of Table 4.4 (negatives are decelerations).

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<sup>50</sup> Milton Abramowitz, 'Elementary Analytical Methods', in *Handbook of Mathematical Functions with Formulas, Graphs and Mathematical Tables*, ed. by Milton Abramowitz and Irene Stegun, 1972, 10th printing with corrections (Washington: Dept of Commerce (National Bureau of Standards), 1964), 9–64.

Average seconds	Bar/Beat	BPM average	BPS average	BPS/S average
0	N/a	N/a	N/a	N/a
6.88	1.4	51.28	0.85	-0.01

Table 4.4 Calculating average rates

The *BPM Average* has been transformed to Beats per Second (BPS) by dividing by 60.

In respect of dynamic levels (loudness), decibels are actually logarithms (powers of 10) that must be averaged using the formula shown in Figure 4.16.  $L_{pi}$  is the  $i$ th decibel value,  $\log_{10}$  is the base 10 logarithm, and  $\log^{-1}$  is the anti-logarithm:<sup>51</sup>

$$10\log_{10}\left[\frac{1}{n}\sum_{i=1}^n\log^{-1}\frac{L_{pi}}{10}\right]$$

Fig. 4.16 Average of dB log values

#### 4.13.6 Derive Symbolic aggregate approximations (SAX)

The next step is to derive the symbolic representation of the PAA transform. SAX is one of several possible symbolic representations of time series that may be used to query, compare and data-mine massive multivariate time-series datasets. There is no specific meaning to the symbols, which may be alphabetic, or alphanumeric. It is emphasised that this overall procedure is premised on reducing the overall amount of data to process. There is no benefit in comparing differences between raw datasets prior to symbol allocation (even after the PAA step). That would remove any justification for symbolic processing, which itself requires significantly lower processing resources, and force the researcher back down a path towards numeric processing and correlation analysis.

SAX is equally applicable to comparing large video and image files as it is to music. The symbol alphabet may be any number of discrete characters, but an

<sup>51</sup> Apple Chan, 'Introduction to Sound', *Manipulation with Decibels*, 2008  
<http://personal.cityu.edu.hk/~bsapplec/manipula.htm>. Accessed: 25 June 2016.

alphabet of 5-10 symbols was found to work well. A standard statistical table of breakpoints that divide a Gaussian distribution into equiprobable regions is allocated to the alphabetic symbols. Table 4.5 shows the probability breakpoints ( $\beta_{n=1:5}$ ) for an alphabet ( $\alpha$ ) of 3, 4 and 5 symbols (abc, abcd and abcde):<sup>52</sup>

$\alpha =$	3	4	5
$\beta_1$	-0.43	-0.67	-0.84
$\beta_2$	0.43	0	-0.25
$\beta_3$		0.67	0.25
$\beta_4$			0.84
$\beta_5$			

Table 4.5 Equiprobable regions of a Gaussian distribution

For a three-symbol alphabet ( $\alpha = 3$ ), any value in the PAA that falls below -0.43 will be classified with symbol *a*. Any value greater or equal to -0.43 but less than 0.43 will be classified with symbol *b*. Any value greater or equal to 0.43 classified with symbol *c* (note the symbols are arbitrary and an alphabet may consist of any useful symbols).

The benefits of this approach to music performance analysis are significant. Where any variable of a musical performance is represented by an arbitrary length symbol string, it is guaranteed that comparisons based on that string are no worse than any other string comparison, or even a comparison based on the complete numerical performance data. Applications that process large amounts of data may benefit from such compression of the data. Lower bounding is a required property of such compressed representations, such that the quantum of dissimilarity between symbolic representations of the original music performance data is guaranteed to be smaller than or equal to the dissimilarity calculated on the original uncompressed performance data. Overall, the symbolisation procedure provides three key advantages over other time-series representations: (1) it reduces the dimensionality of the data by operating on quantised values, (2) it reduces the number of dimensional variables by optionally providing for weighted combinations, and (3) it guarantees, so long as the MINDIST metric is used, to provide a similarity measure that is no worse than (i.e. *lower bounds*) the Euclidean Distance (ED) metric, even if the ED

<sup>52</sup> Placido Montalto and others, ‘Similarity Measures and Dimensionality Reduction Techniques for Time Series Data Mining’, in *Advances in Data Mining Knowledge Discovery and Applications*, ed. by Adem Karahoca, 2012, 39, <http://dx.doi.org/10.5772/49941>.

were calculated on the entirety of the original numeric data. It may be the case that there are different numbers of variates for different performances. We still need a method that can compare these two baskets of values. The method as proposed herein, establishes weighted values for each group of time series. This will still provide appropriate dissimilarity measures. For example, one may wish to compare a 2-variable musical performance with a 4-variable one.

As noted earlier, there are other string comparison tests (other than MINDIST) that could be used to calculate dissimilarity but there is no better dissimilarity estimator than MINDIST.<sup>53</sup>

#### 4.13.7 Calculate Dissimilarity Matrix

The *Saxify* system automates the calculation of DMs. It reads the Excel spreadsheet containing the recording data, one performance tab at a time, and performs all necessary calculations. It can do this for a complete performance and, given a *map* indicating sections of a work, it can also create DMs for each section individually. This facility was included to allow a more detailed examination of performances.

#### 4.14 *Saxify* system

Over 18 months of research was committed to developing the *Saxify* software. A first version was developed in the Java programming language. It was subsequently decided, based on superior data handling characteristics of the R statistical programming language, to abandon the Java version. The R Studio product (version 1.0.143) was used for development, and all of the code has been verified in R language version 3.5.0 nicknamed *Joy in Playing*. The software involves four major parts – *Saxify.R*, *Work.R*, *Section.R* and *Plotter.R*.<sup>54</sup> *Saxify.R* is the control program. It directs two other programs, *Work.R* and *Section.R*, to perform specific tasks (described below) under its

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<sup>53</sup> Valdimir Levenshtein, ‘Binary Codes Capable of Correcting Deletions, Insertions, and Reversals’, *Soviet Physics Doklady*, 10.8 (1966), 707–10.

<sup>54</sup> Please see complete listings of the software in Appendix B. Note that the code is released under a Creative Commons license that allows anyone to use or modify it subject to the limitation that no commercial use may be made of the code nor of any derivative versions.

control. `Work.R` is a class that defines a musical work. It consists of multiple sections, each defined by the `Section.R` class.

`Plotter.R` performs unsupervised machine learning on a Dissimilarity Matrix, using the PAM (Partitioning Around Medoids) technique. We might want answers to a question such as ‘What are the six best groups we can make out of X’.<sup>55</sup> This type of data analysis is important to the *Saxify* procedure since it facilitates visualising patterns in music data that are not readily evident from the tables of numeric data.

It can also generate Silhouette Diagrams to show the strength of a particular PAM scheme and generate Elbow Diagrams to assist the decision as to how many clusters are in the DM data. The PAM technique—k-Medoids clustering—was chosen because it has several advantages over conventional k-Means clustering. It is more tolerant of outliers, and it can take a dissimilarity (or even a distance) matrix as direct input.

Following a data processing run, *Saxify* produces a control report entitled *Performance Analytics* as shown in Figure 4.17. It shows the work processed (‘*Schoenberg Phantasy*’), date and time of the run, number of performances processed, identifier of each performance, calculation of DMs (two separate variables, and combined), section breakdown (two separate variables and combined). Then it reports the Dissimilarity Matrices being calculated, followed by a repeat of this process for each section of the work. Finally, there are some runtime statistics, the most significant being the Elapsed Times for this run (in this case just over seventeen seconds). The performance data (including the PNT) is read from the Excel (or other) data store. Then the software calculates three DMs, one for each variable and one for the variables combined. Finally, a series of three similar DMs are calculated for each section of the music as specified in a *map*. The DMs are all stored in pre-defined folders:

```
Schoenberg Phantasy, op. 47
Performance Analytics
Tue Jun 5 14:12:03 2018
```

```
-----
Process performances data from Excel - (44 performances) ...
```

```
PNT, Koldofsky-Steuer mann51, Varga-Krenek51, Kolisch-Stock53, Kolisch-
Willmann53, Kolisch-Willmann54, Bress-Reiner62, Baker-Gould64, Kolisch-
Johansen65, Menuhin-Gould65, Goldberg-Webster66, Kolisch-Johansen66, Gross-
Grayson74, Gotkovsky-Gotkovsky76, Kremer-Maisenberg77, Kagan-Lobamov78,
```

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<sup>55</sup> Peter Harrington, *Machine Learning in Action* (New York: Manning Publications, 2012), 205.

Veselka-Dratvova85, Arditti-Litwin94, Kremer-Maisenberg94, Israelievitch-Lemelin00, Lang-Lang00, VanDerMeer-Grotenhuis01, Walch-Korber01, Wallin-Pontinen01, Huang-Vainstein02, Koh-Uchida03, Bellini-Gianotti04, Kim-Bowles04, Repin-Lugansky04, Doll-Marton05, Borup-Ernst06, Widmann-Lepper06, Frayanova-Pashchenko08, Colbentson-Appel10, Moller-Oquist10, Revich-Kolodenko10, Schulte-Oldfather10, Yamada-Kynoch10, Anderegg-Funderburk11, Fukuhara-Roden11, David-Gompper12, Soltau-Auvil12, Swenson-Chung12, Degand-Peyrebrune13, Felberg-Gordon13,

Calculating performance Dissimilarity Matrix...3/3  
 Calculating performance Dissimilarity Matrix...2/3  
 Calculating performance Dissimilarity Matrix...1/3

Section - 0: A, Grave I #: 1 of 4 Variable: 3...2...1...  
 Section - 1: B, II #: 2 of 4 Variable: 3...2...1...  
 Section - 2: B', ii #: 3 of 4 Variable: 3...2...1...  
 Section - 3: A, III #: 4 of 4 Variable: 3...2...1...

...Run ended  
 User System Elapsed  
 17.338 0.702 17.284

Fig. 4.17 Run control report

## 4.15 Data storage

Figure 4.16 shows a useful folder/directory structure that is recommended to hold the input and output data. Individual items are described below.

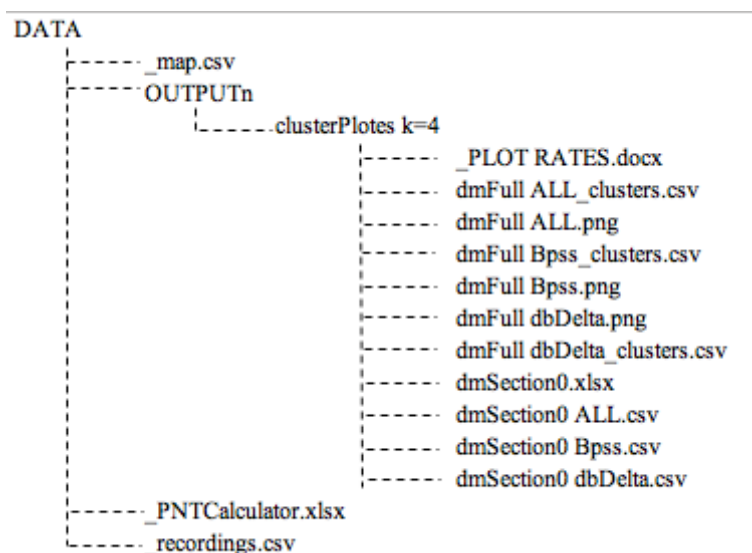


Fig. 4.18 Directory/Folder structure

\_map.csv defines the sectional breakdown of a work. It contains entries that define the structure in terms of its start and end bars. \_PNTCalculator.xlsx holds input data in an

Excel worksheet that is presently used to import and store all performance source data including the Performance Norm (which is automatically calculated on the worksheet from the other tabs). *Saxify* is notified where the relevant variables are stored (as columns on the sheet) by parameters that may be set at run-time. Additional parameters include: the number of symbols to be used in the symbolic approximation step, frame size, weights to be applied to variables when calculating the combined values, and location (folders or directories) for DM outputs. `_recordings.csv` is a simple list of recording identifiers. `OUTPUTn` (where *n* is blank or an integer) defines a high-level folder containing output data created by *Saxify*. It has a sub-folder, `clusterPlots k=4`, that holds output data files. *K=4* signifies that the starting assumption for PAM is 4 clusters. *K* may be any value so long as it is notified to the *Plotter.R* program which uses the value as a starting assumption for the number of clusters.

This folder in turn contains a number of items. File `'dmFULL ALL_clusters.csv'` is a file that holds the cluster identifier assigned to each recording. File `'dmFull ALL.png'` is a realisation of the clustering for the specified variables combined. File `'dmFull Bpss_clusters.csv'` is the assigned clustering for the *Bpss* variable. File `'dmFull Bpss.png'` is the clustering graphic. File `'dmFull dbDelta.png'` is the clustering graphic for the *dbDelta* variable. File `'dmFull dbDelta_clusters.csv'` is the assigned clustering.

These are followed by similar clustering details for each section of the music performances as represented in file `'_map.csv'` and numbered sequentially from `Section0`.

#### 4.16 Chapter summary

Viewing large tables of numbers may be an unproductive way to detect patterns in data. Similarities in musical performance data may better be visualized using *statistical clustering*. This chapter has described the *Saxify* analytical model which: (1) reduces a set of performance variables to a symbolic string, (2) creates a performance norm to represent an *average* performance from a set of music performances, and (3) defines the quantum of dissimilarity between any two performances and between each performance and the PN. The distance between any two strings represents the degree of dissimilarity between the underlying two musical performances. It is calculated in a standard statistical manner by looking up the distances between each pair of symbols in a distance table, squaring the distances, summing them, taking the square root and finally

multiplying by the square root of the compression rate. Symbols that are one or two values apart (for example the combinations a, a or a, b) are treated as having have 0 separation. This helps to eliminate spurious dissimilarities that may arise from random noise in the data. Normal/Gaussian tables may be used to calculate the probability of random occurrence. In statistical terms, the acceptance region at 95% confidence is 1.96 standard deviations from the mean. We may conclude that values below 1.96 are not statistically different from 0. Values greater than 1.96 may be assumed to be statistically different at that 95% confidence level. Since the values in the PAA series were constrained to have identical Gaussian probabilities of selection for symbolic representation, the calculated dissimilarity measures—as expressed by MINDIST—are related to areas under the Gaussian distribution. High values of MINDIST may be assumed to represent real dissimilarity rather than differences that have arisen randomly.

This model will now be validated on sets of Chopin recordings while Chapter 6 will apply it to Schoenberg *Phantasy*.



## Chapter 5 | VALIDATING THE MODEL

Validating *Saxify* was an important next step in the research. It was necessary to show that the model may be applied successfully to pre-existing data. After doing so, it was determined that it can produce results that are comparable to those derived under a different analytical approach targeting Chopin Mazurkas. Those results had been peer reviewed in several journal and conference publications. It is acknowledged that significant further research is appropriate to apply *Saxify* to a wider range of music.

I obtained timing and dynamics data collected by the Mazurka project at CHARM, the AHRC music research centre.<sup>1</sup> This project collected multiple recordings of all Chopin's Mazurka and continues to provide the data in comma-separated value files (CSV) online. I selected randomly two of their datasets covering Mazurka op. 17 No. 4 and Mazurka Op. 68 No. 3. Having assured that the *Saxify* approach arrived at generally similar conclusions to the CHARM research, albeit on a completely different theoretical basis, the approach would then be applied in full to the *Phantasy* op. 47 for Violin with Piano accompaniment (1949), Schoenberg's penultimate composition.<sup>2</sup> One significant benefit of selecting this work is that all its recordings date from the post-78rpm era. In earlier recording periods 'neither speed of revolution nor tuning were standardized'.<sup>3</sup> So we can be reasonably sure that the performance tempi and dynamics reflect recording session performance realities.

### 5.1 Published results

An important research project at CHARM had exposed the so-called 'Joyce Hatto hoax' even before music critics, such as *Gramophone's* James Inverne, had raised questions in print.<sup>4</sup> This research project developed a substantial database of timing and dynamics data for over 1,500 recordings of Chopin's Mazurkas, including nearly thirty complete

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<sup>1</sup> <http://www.charm.rhul.ac.uk/index.html>, Accessed: 24 January 2017.

<sup>2</sup> Arnold Schoenberg, *Phantasy for Violin with Piano Accompaniment*, Peters Edition 6060 (New York: Peters, 1952). and Arnold Schoenberg, *Phantasy for Violin with Piano Accompaniment* (New York: Peters, 1973).

<sup>3</sup> Nicholas Cook, 'Performance Analysis and Chopin's Mazurkas', *Musicae Scientiae*, XI.2 (2007), 188. For this reason, there might be significant issues in applying the model to earlier recordings.

<sup>4</sup> James Inverne, 'Masterpieces or Fakes? The Joyce Hatto Scandal', *Gramophone*, 21 February 2007, <http://www.gramophone.co.uk/editorial/masterpieces-or-fakes-the-joyce-hatto-scandal-february-15-2007>, Accessed: 21 December 2013.

sets. This important body of data continues to be made freely available at ‘The Mazurka Project’ website. Nicholas Cook and Craig Sapp (referred to hereinafter as Cook-Sapp) generated timing and dynamics data for many of the Mazurkas. They have published several journal and conference papers that addressed the data.<sup>5</sup>

Cook-Sapp applied Pearson Correlation Coefficients, coupled with clever visualization techniques, to compare relative timings and dynamics. The visualization techniques (*Scapeplots*) related different recordings in terms of their closeness.<sup>6</sup> This is inversely related to the objectives of the present research’s *Saxify* model which compares recordings in terms of dissimilarity. The Cook-Sapp techniques focus on relative timings and relative dynamic levels rather than absolute ones, even if manipulations take place during its production processes. This is a similar objective that *Saxify* set out to meet.

Cook-Sapp showed, with a high degree of certainty, that the Joyce Hatto recording of Chopin’s Op. 68 No. 3 is ‘indistinguishable from that on a commercial recording credited to Eugen Indjic’.<sup>7</sup> Furthermore, they also showed that the Hatto and Indjic recordings of Mazurka Op. 17 No. 4, released in the same recording set, also ‘are virtually indistinguishable’.<sup>8</sup>

They achieved both these findings by showing that the correlation coefficients for both pairs of recordings, calculated on the entirety of available music data, were so close to 1.0 as to make it highly likely that they were identical in each case. In order to arrive at this conclusion, they calculated correlations on the entire performance data sets.

## 5.2 Cook-Sapp versus *Saxify*

*Saxify* was used to re-process the published Cook-Sapp data, together with their peer-reviewed results as detailed in their various conference and journal publications. The validation procedure tested whether *Saxify* could use the Cook-Sapp data to generate

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<sup>5</sup> Including Cook, Nicholas, ‘Changing the Musical Object: Approaches to Performance Analysis’, in *Music’s Intellectual History: Founders, Followers, and Fads* (New York: RILM, 2009), 775–90. See also Sapp, Craig, ‘Computational Methods for the Analysis of Musical Structure’ (PhD dissertation, 2011).

<sup>6</sup> Cook, Nicholas and Sapp, Craig, ‘Purely coincidental? Joyce Hatto and Chopin’s Mazurkas’ [http://www.charm.kcl.ac.uk/projects/p2\\_3\\_2.html](http://www.charm.kcl.ac.uk/projects/p2_3_2.html), Accessed: 25 May, 2017, also published by IRCAM as Nicholas Cook and Craig Sapp, ‘Une Pure Coïncidence? Joyce Hatto et Les Mazurkas de Chopin’, trans. by Jean-François Cornu, *L’étincelle: Le Journal de La Création À l’IRCAM*, 3 (2008), 19–21.

<sup>7</sup> (Calliope label: *Intégrale des mazurkas*: Frederic Chopin, 3321).

<sup>8</sup> <http://www.mazurka.org.uk/>, Accessed: 25 May 2017.

DMs and identify the Hatto fraud with very high precision by showing certain recordings had very low dissimilarities. Cook-Sapp did not publish results for individual segments of these two Mazurkas.

The  $H_0$  null hypothesis, for model validation purposes, is that there is no difference between the Hatto and Indjic recordings. I used *Saxify* to calculate a set of DMs for absolute beat-based timings. This process was repeated for rates of acceleration/deceleration.<sup>9</sup>

One notable limitation, in the data reported by Cook-Sapp, is that they appear to have calculated average decibel levels by using simple arithmetic averages of sound pressure levels. Decibels are logarithms—therefore simple arithmetic averages of values are not appropriate. The correct formula for calculating average decibels is discussed in §4.13.5 above. It was decided, for this reason, not to compare dynamic levels calculated on the *Saxify* basis with the Cook-Sapp averages for dynamics.

	Performance variable measured	Cook-Sapp r	<i>Saxify</i> MINDIST
<u>Op. 68 No. 3</u>	BPM	0.996	0.43
	Bpss	n/a	1.60
<u>Op. 17 No. 4</u>	BPM	0.996	0.00
	Bpss	n/a	0.00

*Table 5.1 Summary results of the two approaches*

Cook-Sapp measured neither acceleration rates nor rates of change of dynamics. In their approach, a correlation value of 1.0, defined as a perfect positive correlation, would show that a pair of recordings is truly identical at least for the values of the variable(s) being measured. Both the Cook-Sapp and *Saxify* results are summarized in Table 5.1 above. For *Saxify*, a dissimilarity measure (Mindist) of 0 would demonstrate two recordings are identical, for the values of the variable(s) being measured. Cook-Sapp calculated correlations of 0.996 for each pair of recordings. The real differences in their results (0.004 for each Mazurka) were due to human and random errors in measuring timing data: near-perfect correlations strongly support a hypothesis that the Hatto

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<sup>9</sup> Eamon O Doherty, ‘Saxify: Detecting Fraudulent Music Recordings’ (presented at the SMI/ICTM-IE Annual Postgraduate Conference, Maynooth University, 2018).

recordings, in both these cases, were re-mastered versions of the Indjic ones.<sup>10</sup> The Cook-Sapp work was further supported by comparison with other recordings of the same works. Their average correlation across all recordings of Op. 17 No. 4 was 0.641.

*Saxify* analysis of Op. 68 No. 3 produced a dissimilarity value, between Indjic and Hatto, of 0.43 for the BPM variable. This is extremely low in absolute terms—a value close to 0 represents low dissimilarity (high similarity). The indicated 0.43 value is also noteworthy because *Saxify* placed the Hatto recording relationships to other recordings in a range from 2.82 (Kapell) to 9.00 (Block)—none are a likely Hatto clone. The resulting value of 0.43 is well within the acceptance zone and has no significance. For the acceleration variable, Bpss, *Saxify* determined a result of 1.60, again very low in relation to dissimilarities from all other recordings in the range 4.19 (Kapell) to 9.49 (Shebanova). The Cook-Sapp average correlation across all recordings of Op. 68, No. 3 was 0.782.

The *Saxify* analysis of Op. 17 No. 4 produced a dissimilarity value between Indjic and Hatto of 0.00 for the BPM variable. As noted above, the closer a dissimilarity is to 0.00, the more likely it is that they are identical. The relationships of the supposed Hatto recording to other recordings range from 5.32 (Falvay) to 9.31 (Perahia). For the acceleration variable, Bpss, *Saxify* also determined a result of 0.00. This may be contrasted with dissimilarities from all other recordings in the range 3.49 (Shebanova) to 7.75 (Horowitz).

Accordingly, having produced no evidence to falsify  $H_0$ , I concluded that *Saxify* supports the Cook-Sapp results that there are no differences between either pair of Hatto and Indjic recordings of the two Mazurkas.

There are two additional important results of this validation work: (1) *Saxify* can arrive at the same conclusions as a correlation analysis performed against complete sets of performance data, and (2) arbitrarily compressed symbolic representations of the recordings are satisfactory data on which to ground such strong conclusions. This supports the general point made earlier about the Mindist dissimilarity measure.

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<sup>10</sup> Nicholas Cook and Craig Sapp, *Ibid.*, 19–21.

### 5.2.1 Clustering analysis

A *cluster analysis* is a process that enables us to classify data items, on some arbitrary basis, by measuring relationships. The relationships may be defined in terms of closeness (using some appropriate measure) or (as in *Saxify*) in terms of dissimilarity. Classification can use many different classification algorithms. The end result aims to provide a visualisation of a complex dataset to make it easier to interpret in two-dimensional space.

I used the *Saxify* results to perform such a cluster analysis using the well-understood technique: Partitioning Around Medoids (*PAM*).<sup>11</sup> A *medoid* is a performance data point within a cluster for which the sum of the distances between it and all the other performances in the cluster is a minimum. The PAM technique is: (a) specifically designed to accept a DM as input, and (b) less prone to influences from outliers than alternative techniques, such as K-Means clustering of the original data.

Cook-Sapp used Pearson correlation coefficients as a proxy for *closeness*, where a correlation of 0.0 indicates no relationship, and a correlation of 1.0 indicates identity. This proxy enabled them to develop a cluster analysis to show the closeness of relationships between different recordings, and to visualise how recordings bunch together in groups (although their cited paper does not discuss the specific clustering algorithm they used).<sup>12</sup>

Having a DM to work with ensures the lowest amount of computation is required. PAM-type clustering algorithms, using unsupervised machine learning techniques, require a choice in advance as to the likely number of performance clusters. This choice is not strictly arbitrary. It has to balance maximal compression of having just one performance cluster (little information) and maximum accuracy by making each performance data point its own cluster (pointless). A common method to determine a likely number of PAM clusters is the *elbow* criterion. This criterion chooses a number of clusters so that adding another cluster adds incrementally very little information. The *elbow* is identified by plotting the ratio of Within Cluster Variance (WCV) to Between Cluster Variance (BCV) against different numbers of clusters. WCV estimates average

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<sup>11</sup> Martin Maechler and others, 'PAM', in *Finding Groups in Data: Cluster Analysis Extended* (CRAN, 2017), 45, <https://cran.r-project.org/web/packages/cluster/cluster.pdf>. Accessed: 20 January 2017.

<sup>12</sup> Nicholas Cook and Craig Sapp, *Ibid.*, 19–21.

variability in the specific musical variables used to assign performances (or segments thereof) to a particular cluster. BCV estimates average variability between clusters.

The overall objective of cluster analysis is to assign performances to clusters that simultaneously minimize WCV and maximize BCV. Therefore, as the number of clusters is increasing, the ratio of the WCV to the BCV will keep decreasing. Eventually the incremental, marginal gain from adding one extra cluster will drop, producing an angle in the graph (the *elbow*). I used this technique to plot the percentage of variance explained by the clusters against a range of clusters from one to an arbitrary ten and determined that a set of four was found to produce optimal clustering for the available performance data.

Figure 5.1 shows the PAM clusters plotted using the Cook-Sapp data for Chopin's Mazurka Op. 68 No. 3. This explains approximately 66% of the variability in the underlying optimal clustering. Saxify produces some differences from the Cook-Sapp results but there are significant similarities. The differences may be due to Cook-Sapp ignoring two recordings in their clustering, but for which they actually publish data. These are the Lushtak 2004 and Kappell 1951 recordings, neither being included in their clustering diagrams:

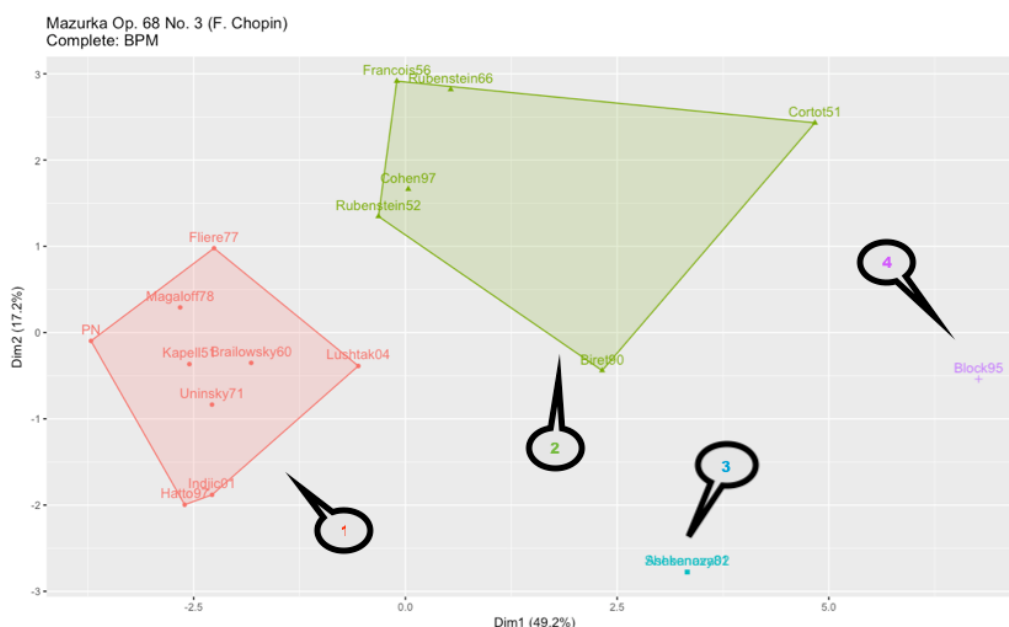


Fig. 5.1 Clustering BPM Cook-Sapp data for Op. 68 No. 3

### 5.2.2 Points of difference

Referring to Fig. 5.1 above, which is a clustering based on the complete recordings of Mazurka Op. 63 No. 3, the *Saxify* approach does produce some differences from the Cook-Sapp analysis:

- *Saxify* determined that the Block 1995 recording is an outlier.
- Cohen 1997 is clustered on the topmost, green cluster in Figure 5.1 whereas Cook-Sapp located it somewhat more away from the Cortot 1951/Biret 1990/Francois 1956 cluster.
- *Saxify* places Francois 1956 closer to both the Rubenstein 1952 and Rubenstein 1966 recordings than Cook-Sapp.
- Cook-Sapp rate Indjic 2001 (and therefore Hatto 1997) as closer to Cortot 1951/Biret 1990/Francois 1956.
- One initially surprising result from *Saxify*, using timing data for the complete work in Figure 5.1, is that the Shebanova 2002 and Ashkenazy 1981 recordings are co-incident at bottom right, overprinted as turquoise-coloured Cluster #3. They are determined by *Saxify* to have zero dissimilarity. This result could indicate a possibility that the recordings actually have the same source. However this *Saxify* cluster result only applies to tempo measures taken alone, since Cook-Sapp do not include dynamic levels in their clustering calculation. When dynamics are included in *Saxify*, the recordings are still determined to be close but not identical.

### 5.2.3 Saxify similarities with Cook-Sapp

- Both the *Saxify* and Cook-Sapp analyses locate the Rubenstein 1952 and Rubenstein 1966 performances close to each other, and within the same cluster.
- The recordings that Cook-Sapp located close to their ‘tempo average’ are largely the same ones clustered by *Saxify* with the PN.
- Hatto and Indjic are clustered very closely together in terms of their measured dissimilarity.
- Cortot 1951 is located close to both Biret 1990 and Francois 1956.

### 5.3 Cook-Sapp extension

Cook-Sapp extended their analysis by suggesting that performances may be related based on analysing timings only for the first 32 bars of each recording of Op. 68 No. 3. They suggest that this eliminates the effects of relationships between sections. Their reasoning was that several pianists play the *Poco più vivo* section considerably faster than the outer sections of the work. When *Saxify* data is clustered for these 32 bars alone, the results are more similar to Cook-Sapp (see Fig. 5.2): Ashkenazy, Indjic and Biret move closer together and into the same cluster.<sup>13</sup> A notable finding by *Saxify* is that timings in these 32 bars cause Indjic and Hatto to appear dissimilar. Yet, on an overall basis for the complete work, they are identical. This demonstrates the extent of the manipulation that was performed on only portions of the original recordings and shows the importance of including as many variables as is practicable, and of studying a complete performance as well as its sections. This explains approximately 86% of the variability in the underlying optimal clustering.

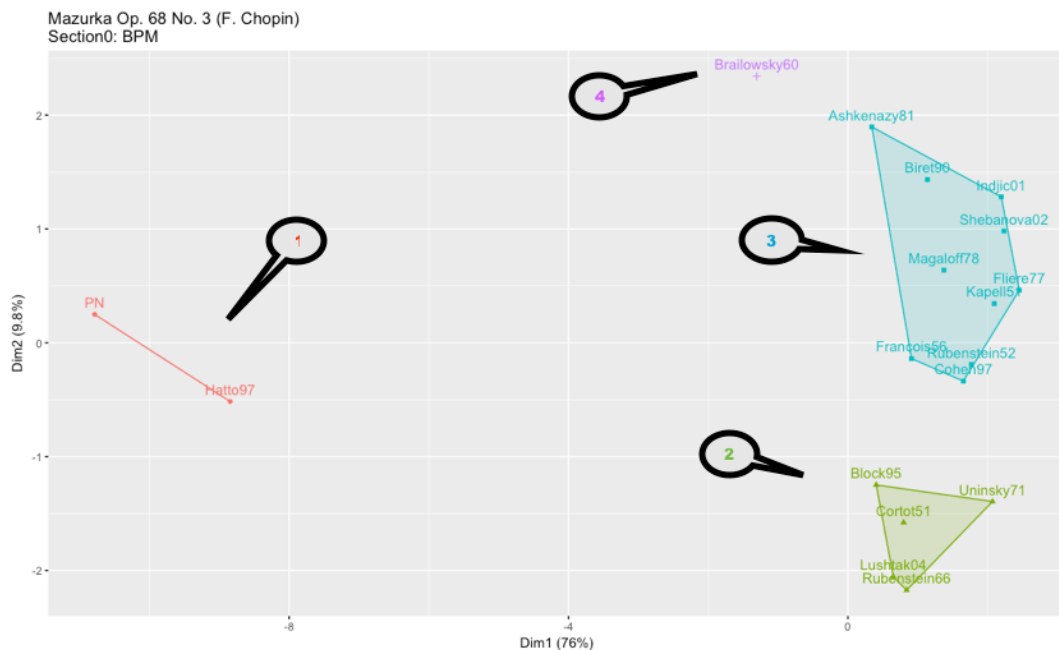


Fig. 5.2 Clustering BPM data based only on Bars 1-32 Op. 68 No. 3

### 5.4 Chapter summary

There are several useful conclusions to be drawn from the validation experiments. It is clear that *Saxify* can help to identify recordings that are likely to be one and the same, with a high probability of detecting a hoax. The Cook-Sapp findings are strongly

<sup>13</sup> Cook, 'Performance Analysis and Chopin's Mazurkas', 203.



corroborated by *Saxify*, although some results will never be identical, since both approaches rely on an entirely different treatment of musical data.

The nature of a DM has been demonstrated to be useful in discriminating recordings. Since MINDIST is not truly metric, gauging dissimilarity rather than distance, we cannot say that one recording is X times further away than another. However, we can certainly say that higher values indicate a higher probability of true dissimilarity between the originating recordings. A significant benefit of *Saxify*, since it operates on an arbitrarily reduced dataset (after PAA and transformation to a symbolic representation), is that analysis is not limited to recordings as short as the Chopin Mazurkas.

Clustering analysis, using the DM and PAM clustering, does not of itself introduce new information. What it achieves is to present a human-readable visualisation of possible relationships in the underlying musical data. It also facilitates comparison of results from *Saxify* with other ways of measuring the strength of relationships between different performances.

## CHAPTER 6 | CASE STUDY: EXPRESSIVITY IN THE *PHANTASY*

Chapter 5 demonstrated how *Saxify* can validly quantify performance dissimilarities for Chopin *Mazurkas* using tempo and dynamics data. This present chapter moves a step further by developing an experimental case study around the Schoenberg *Phantasy*. The overall objective is to evaluate expressive styling of complete recorded performances, and of segmentations of those recordings using *performance maps*. These maps will be generated on the basis of the alternative structural theories already discussed at §3.3.

### 6.1 Three hypotheses

There are three hypotheses that shall be tested experimentally. The first hypothesis is that low dissimilarities between one or more pairs of recordings are such as to indicate a possible Hatto-style manipulation. This would require zero or very low dissimilarity between a pair of recordings using their multi-variate *performance fingerprints*.

The second hypothesis is that expressive performance style has changed measurably over six decades of recordings when considering the *Phantasy* as a whole. This would be indicated by significant trending in dissimilarities towards or away from the PN. In this respect we are not concerned with absolute levels of variability but whether the spread of variability is increasing or decreasing. A significant increase in variability might show disagreement as to appropriate ways of styling a performance.

Alternatively, it might demonstrate more risk taking or significant performance style innovations in respect of specific factors.

The third hypothesis is that expressivity, as delivered by experienced musicians, is a very localised phenomenon and does not communicate any intensity characteristics across a complete work. This hypothesis is grounded in the idea that expressive performance is not concerned with a musical work taken as a whole. It implies that expressivity is fundamentally bound up with communicating individual structures, at some local level, be they phrases or formal sections. In order to test this third hypothesis, it was decided to compare the relationships indicated by performances according to the proposals, as indicated in Chapter 3, of Lester, Polansky, Stein and Tipton. This involved exploring how these structural theories may or may not be

evident from performance data. It should be noted that these theories address the notion of structure quite independently of individual movements or phrases.

## 6.2 Representing expressivity in the data

Two pairs of performance variables, measured at each beat, were selected to represent expressivity: (1) point acceleration (Bpss) with point rate of change of dynamics (dBDelta), and (2) tempo in beats per minute (BPM) with absolute value of dynamics (dB<sub>spl</sub>).

## 6.3 Correlated variables

As in many multivariate explorations of data, it is critical to ensure that independent music data variables (the measured values) are not related to each other. The consequences could weaken or most likely invalidate statistical conclusions. Pearson Correlation Coefficients (commonly referred to as *r*) were calculated for each pair of variables (BPM with dB<sub>spl</sub> and Bpss with dBDelta) as shown in Table 6.1 below. An *r* value of close to 1 (or -1) would indicate that variables may be highly related. Values close to 0 (whether positive or negative) indicate a low degree of relationship.

Recording	<i>r</i> #1	p value	<i>r</i> #2	p value
	BPM to dB		Bpss to dBDelta	
PN	0.325	0.027	0.098	0.521
Koldofsky-Steuer mann51	0.269	0.073	-0.071	0.643
David-Gompper12	0.135	0.376	-0.075	0.624
Varga-Krenek51	-0.083	0.587	-0.033	0.829
Kolisch-Stock53	-0.069	0.652	0.052	0.734
Kolisch-Wilmann53	0.234	0.121	-0.241	0.110
Kolich-Wilmann54	0.298	0.046	-0.224	0.139
Bress-Reiner62	0.121	0.428	-0.160	0.293
Baker-Gould64	0.156	0.306	-0.071	0.643
Kolisch-Johansen65	0.316	0.034	-0.049	0.749
Menuhin-Gould65	0.066	0.666	-0.098	0.521
Goldberg-Webster66	0.175	0.250	-0.138	0.365
Kolisch-Johansen66	0.156	0.306	-0.214	0.158
Gross-Grayson74	0.169	0.267	-0.014	0.927
Gotkovsky-Gotkovsky76	0.205	0.176	-0.142	0.352
Kremer-Maisenberg77	0.143	0.348	-0.110	0.471
Kagan-Lobamov78	0.250	0.097	-0.018	0.906
Veselka-Dratvova85	0.304	0.042	-0.132	0.387
Arditti-Litwin94	0.224	0.139	-0.112	0.463
Kremer-Maisenberg94	0.231	0.126	-0.190	0.211
Israelivitch-Lemelin00	0.126	0.409	0.254	0.092

Lang-Lang00	0.251	0.096	-0.054	0.724
VanDerMeer-Grotenhuis01	0.209	0.168	-0.122	0.424
Walch-Korber01	0.150	0.325	-0.039	0.799
Wallin-Pontinen01	0.262	0.082	-0.129	0.398
Huang-Vainstein02	0.058	0.705	-0.034	0.824
Koh-Uchida03	0.135	0.376	-0.079	0.605
Kim-Bowles04	0.142	0.352	-0.139	0.362
Bellini-Gianotti04	0.179	0.239	-0.081	0.596
Repin-Lugansky04	0.256	0.089	-0.026	0.865
Doll-Marton05	0.309	0.038	-0.033	0.829
Borup-Ernst06	0.220	0.146	0.015	0.922
Widmann-Lepper06	0.232	0.125	-0.284	0.058
Frayonova-Pashchenko08	0.130	0.394	0.073	0.633
Colbentson-Appel10	0.179	0.239	-0.076	0.619
Mulloer-Oquist10	0.148	0.331	0.054	0.724
Revich-Kolodenko10	0.058	0.705	-0.081	0.596
Schulte-Oldfather10	0.189	0.213	0.157	0.303
Yamada-Kynoch10	0.232	0.125	-0.007	0.963
Arderegg-Funderburk11	0.009	0.953	0.014	0.927
Fukuhara-Roden11	0.267	0.076	-0.104	0.496
Soltau-Auvil12	0.281	0.061	-0.092	0.547
Swenson-Chung12	0.147	0.335	-0.019	0.901
Deygand-Peyrebrune13	0.023	0.880	-0.074	0.629
Felberg-Gordon13	0.059	0.700	-0.099	0.517

*Table 6.1 Pearson correlations and probabilities of occurrence*

Columns 3 and 5 (using two-tailed tests for 45 sample pairs at the  $\alpha = 0.01$  level of significance) show the p values for statistical significance testing of the correlation values in columns 2 and 4 respectively.<sup>1</sup> Each sample pair involves over 400 values. Probabilities less than  $\alpha$  could indicate some possible evidence of correlation. There are no indications at the 0.01 level, for either pair, that any of the available recording(s) should be eliminated from further analysis. Since there is no strong argument in favour of the chosen  $\alpha$  level, and since there are only some marginal indications at the  $\alpha = 0.05$  level, it was decided to include all recordings in further analysis.

#### 6.4 Common influencers

It seems unlikely that significant differences in the parameters of musical performance would arise randomly in time. An evolution in how music actually sounds has already been discussed at §1.10 in respect of singers and orchestras driven in large part by the influence of modern recording technologies. In the era of recorded sound and accessible

<sup>1</sup> Jeremy Stangroom, *P Value from Pearson (R) Calculator* (Social Science Statistics, 2019), <https://www.socscistatistics.com/pvalues/pearsondistribution.aspx>, Accessed: 18 December 2019.

transportation, musicians could listen more closely to the sounds that were being produced by themselves and by others. Recordings can provide areas of common reference for the sharing and development of musical performance characteristics. There is already a body of scholarly research on how music performances might be subject to change: Leech-Wilkinson in one of his analyses, for example, proposes a ‘phonograph effect’, meaning the influence of recordings in causing change.<sup>2</sup>

## 6.5 Discussion of overall durations

Figure 6.1 shows that the average performance duration (from the onset of the first sound to the end of the last one, within the bounds of measurement error) of the *Phantasy*, for the period under review, is 531.64 seconds, being equivalent to the actual duration of the PN. The maximum is 621.19 seconds (Varga-Krenek51) and the minimum is 437.17 seconds (Gross-Grayson74). It may be seen that the variability (spread) of durations was generally wider in the period 1950–1980. After a significant gap from 1980 to 2000, many more recordings of the *Phantasy* emerged, but the general variability of performance durations lessens considerably.

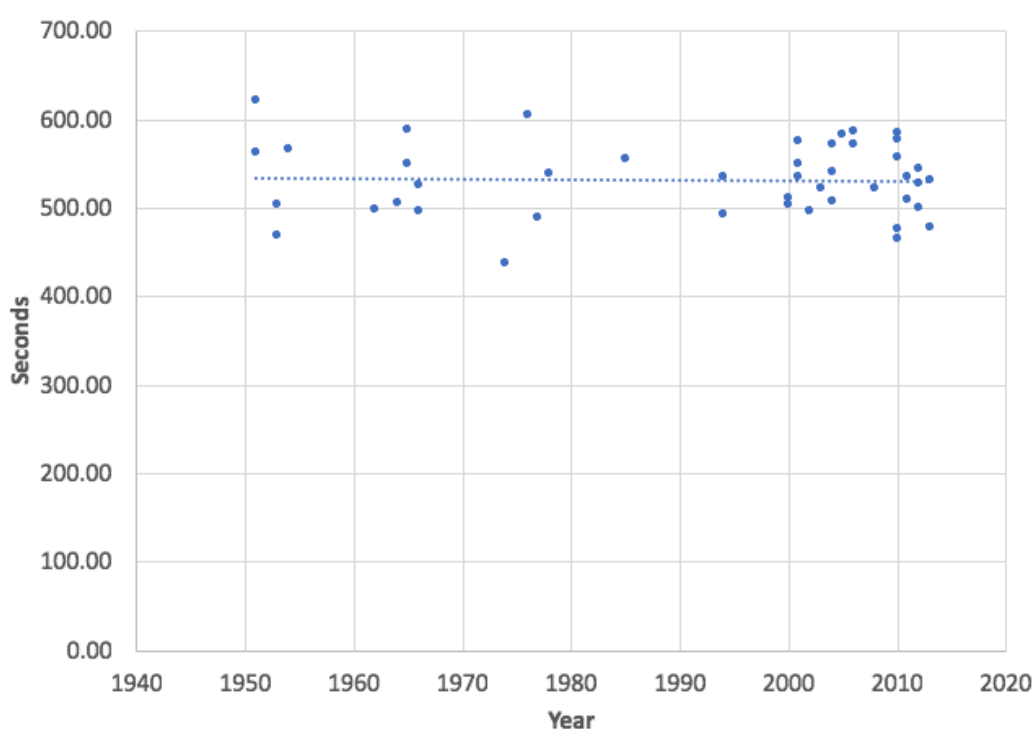


Fig. 6.1 Recording durations in seconds

<sup>2</sup> Daniel Leech-Wilkinson, ‘Portamento and Musical Meaning’, *Journal of Musicological Research*, 25.3–4 (2010), 236.

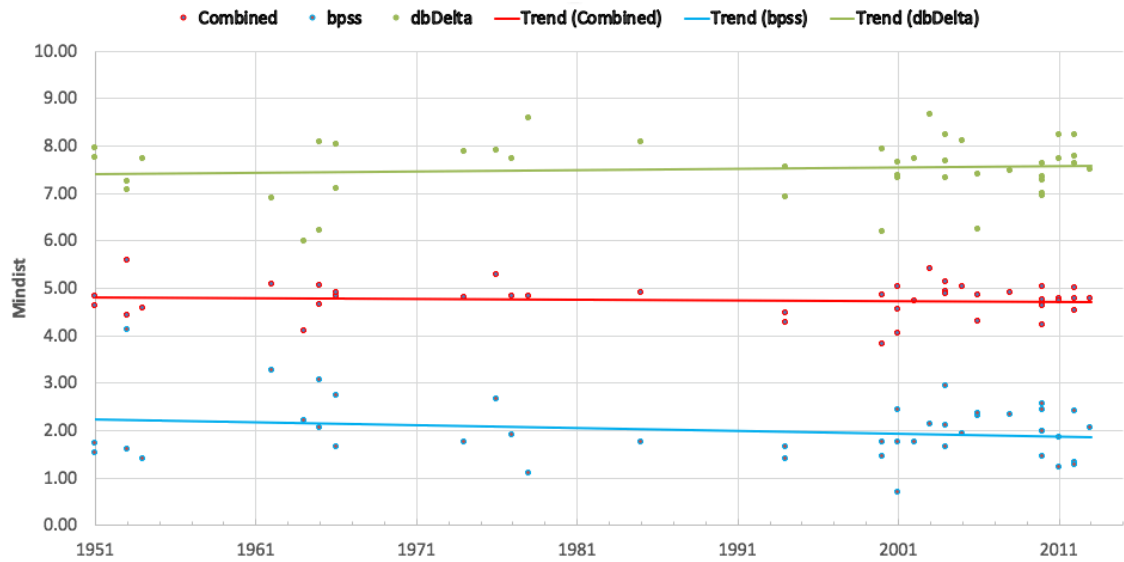
Numerically, the duration range (difference between maximum and minimum values) in the 1950–80 period is 184.02 seconds. The duration range in the 1981–2013 period is 121.75 seconds. For the final seven recordings, after 2010, the duration range drops to 65.27 seconds. There is no significant trend discernible in this plot of overall durations, as indicated by the almost-horizontal trend line. It may be concluded that overall performance duration for this work remains quite stable throughout the period. However, there is a marked clumping of durations close to the regression line that presents fewer candidate outliers in the later period.<sup>3</sup> This demonstrates increasing consistency in overall performance duration.

Figure 6.2 below graphs absolute distances from the PN (dissimilarities) for the rates of change variables. Figure 6.3 graphs corresponding raw values of BPM and dB<sub>spl</sub>. On both graphs, each variable is plotted separately, as well as in combination. Linear Regression was applied to the datapoints to present trend lines. The red lines indicate the Combined value of both variables (bpss and dbDelta). The green lines represent the dbDelta variable. The blue lines represent the bpss variable.

The horizontal X-axis shows the chronological order of performances. The vertical Y-axis shows distances of each recording from the PN.

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<sup>3</sup> Regression (most commonly Linear Regression) means finding the best-fitting straight line through a set of points by minimising the sum of squared distances. See Lane, David, 'Introduction to Linear Regression', in *Online Statistics Education: A Multimedia Course of Study* ([Http://Onlinestatbook.Com/](http://Onlinestatbook.Com/)), ed. by David Lane (Rice University) <http://onlinestatbook.com/2/regression/intro.html>, Accessed: 28 June 2018.



*Fig. 6.2 Distances of Recordings from the PN (BPSS and dbDelta)*

Over the period covered by the recordings in Figure 6.2, the tendency of the combined variables (as shown by the red trend line) can be seen to be stable, almost horizontally linear. There is a slightly greater degree of variability in the earlier period as shown by the spread of values around the trend line. In Figure 6.3, the raw timing and dynamics data obtained similar results as in Figure 6.2, yet the combined variable is notably tighter against its trend after 1971.

In respect of both graphs it can be seen that the absolute dissimilarities are reasonably close to their norm (horizontal axis) for timing variables. But the dynamics are both much more distant from their norm than the tempo values. This indicates that overall dissimilarities, being the combination of both variables, are much more influenced by differences in treatments of loudness (and rates of change) than by tempo (and the corresponding rates of change).

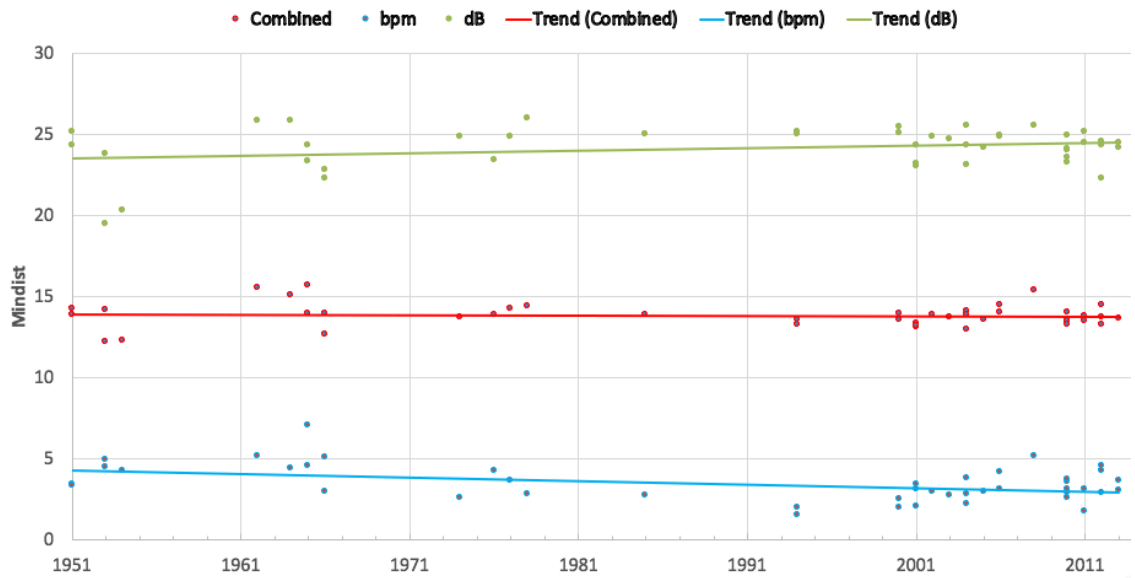


Fig. 6.3 Distances of Recordings from the PN (BPM and db)

## 6.6 Exploratory data analysis

An *exploratory data analysis* (EDA) allows a researcher to derive meaning from trends and patterns and to use data to propose alternative models. A most important part of EDA is to apply algorithms to locate data points based on their relationships—a process termed *clustering*. For present purposes, the relationships are represented by the dissimilarities measured in the DMs and visualized using the PAM partitional clustering strategy, using the approach discussed at §4.14 above. Such clustering methods allow for cluster overlaps. A recording will be allocated optimally to a specific cluster but may present in the intersection space of more than one cluster. In the clustering analyses that follow (Figs. 6.4 and 6.5), generated from the DMs for BPM/db<sub>SPL</sub> and Bpss/dbDelta. The label on each cluster has no importance other than to provide a cluster identification. Recordings are represented as data points in this multidimensional space.

In the first plot (Fig. 6.4) it is notable that all of Kolisch’s recordings, made over a 12-year period, cluster quite close together. This strongly supports the proposition that a



performer can maintain a pattern of timing expressivity over an extended period of time as was already discussed in §1.2. The result demonstrates that the early Kolisch-Stock recording acts as a fundamental exemplar for performances that follow, particularly so given Kolisch's relationship to Schoenberg and profound knowledge of how the composer wanted his music rehearsed and performed.

The closest recording to the PN of the entire set is Kolisch's 1953 recording with Else Stock. Another interesting feature of this clustering result is that the majority of recordings in Cluster #4 are from 2000 onwards while those recordings in Cluster #3 (although not all) are from an interim period following the 1950s. This appears to indicate that *Saxify* has identified a time-related characteristic (for BPM and dB) in the expressivity of the performances. The clustering accounts for nearly 80% of variability in the dissimilarity measurements.

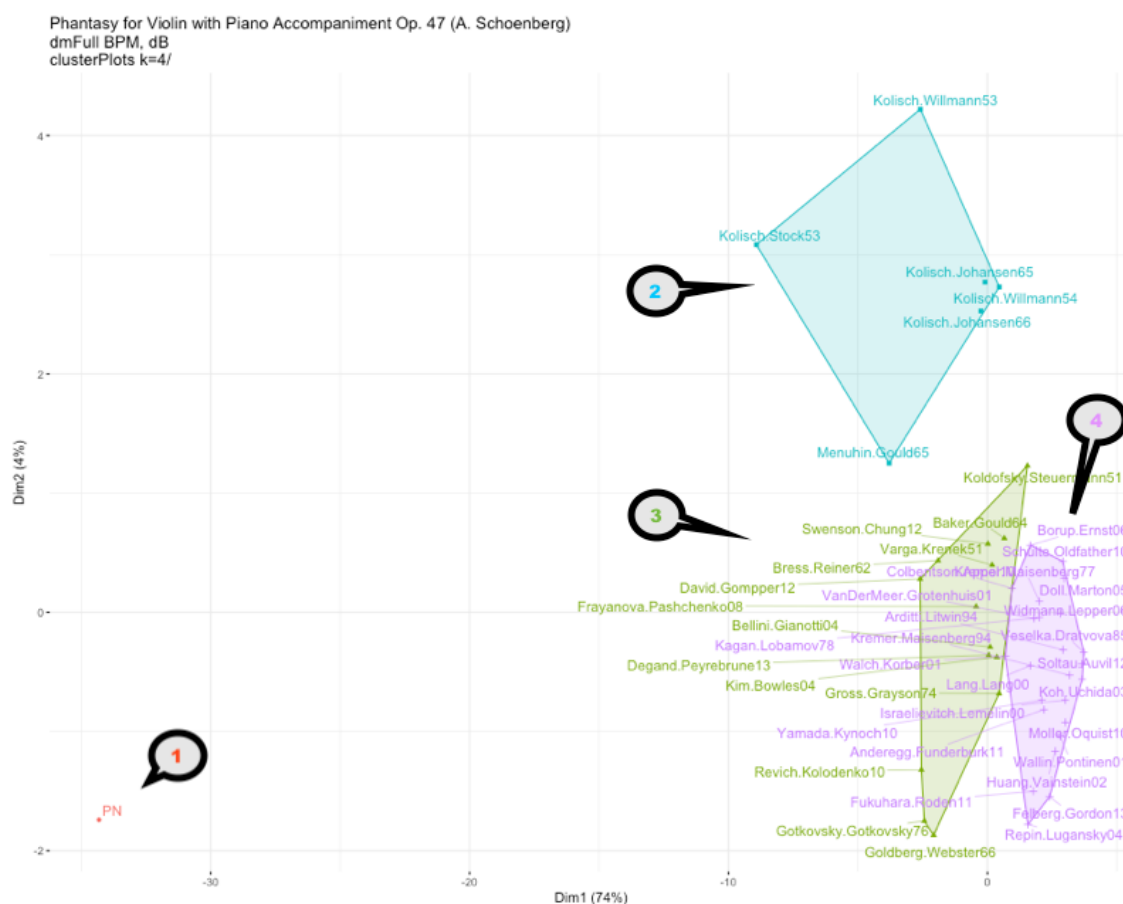


Fig. 6.4 PAM Cluster Plot – BPM and dB combined

The second plot (Fig. 6.5), using Bpss and dbDelta, considerably changes the clustering results with only 56% of the variability accounted for: Kolisch-Stock is still closest to

the PN although now attached to Cluster 2, while the remaining Kolisch recordings, accompanied by Willman, Steuermann and Johansen, are split between two clusters.

In this plot, Kolisch-Stock is firmly located with the PN. While the clustering pattern is less clear than the previous plot, most of the Kolisch recordings cluster together in Cluster 2 along with recordings from the later period. Cluster 3 is mainly recordings of the later period. Cluster 4 is relatively evenly balanced. It seems possible that other factors are influencing the Bpss/dbDelta DMs such that it will in future be worth adding other variables to the mix. Menuhin-Gould65 moves away from the Kolisch recordings when rates of change variables are used. But it now clusters closer to Baker-Gould64 which may point to significant influence by the pianist.

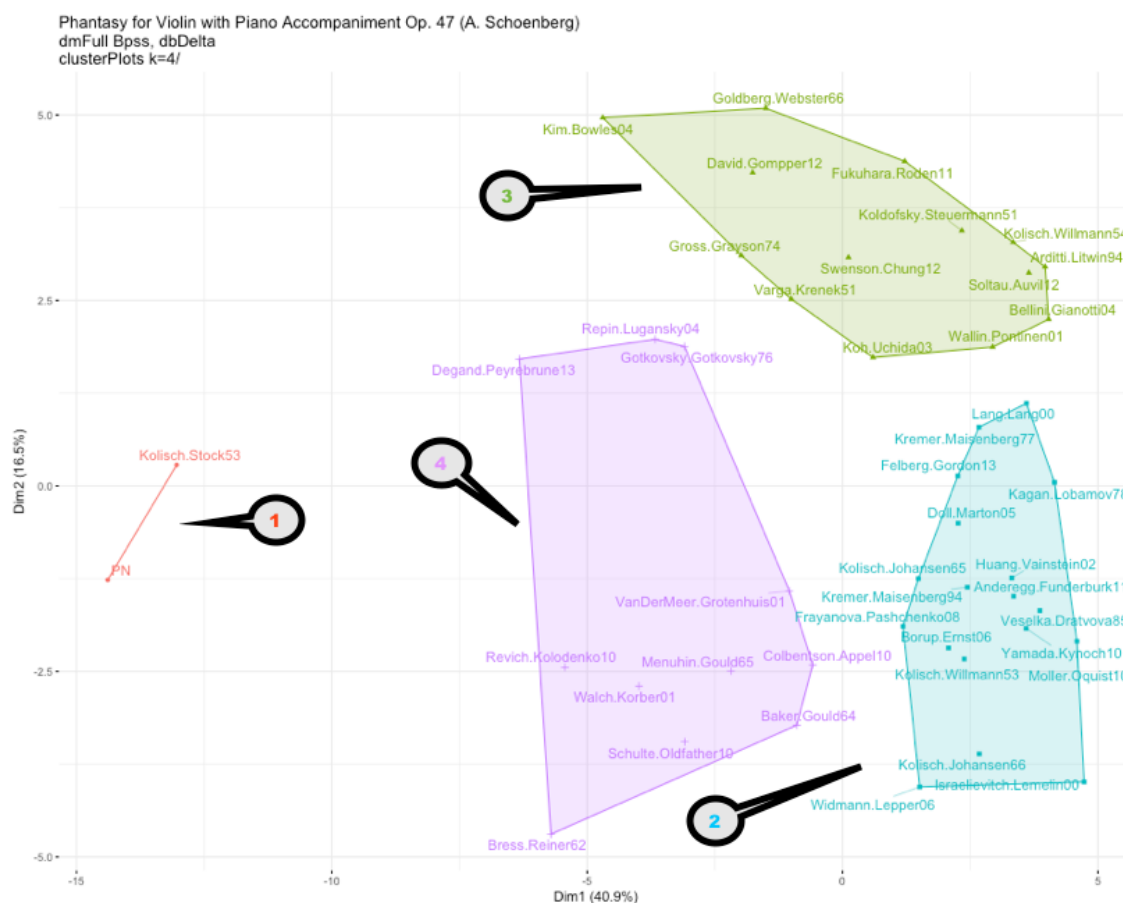


Fig. 6.5 PAM Cluster Plot – bps & dbDelta

## 6.7 Hypothesis #1 – fraudulent manipulation

It may be readily ascertained, from the first two DMs (see Appendix A), that no pair of recordings may clearly be identified as identical. Some recordings are less dissimilar when using the Bpss/dbDelta variables: Moller places closely to the Kolisch recordings,

and to Kagan, Veselka, Israelivitch, Lang, Bellini and Yamada. On the BPM/dBspl variables there is no agreement on any of these.

Accordingly, it is concluded that these results serve to falsify Hypothesis #1. There is no evidence that can be detected by *Saxify* of a Hatto-like fraudulent manipulation in the set of *Phantasy* performances available for this research using either of the variable pairs selected.

## 6.8 Hypothesis #2 – expressivity of the complete work

In order to test whether overall levels of expressivity changed over the sixty-year period of the available recordings, it was decided to examine whether there is a significant trend exhibited by either the BPM/dB pair or the Bpss/dBdelta pair. Figures 6.2 and 6.3 do show a slight divergence of trends for individual performance variables. However, in both graphs, the combined trends are virtually parallel to the x-axis.

On that basis, Hypothesis #2 is falsified by the results — average expressivity has remained virtually unchanged over time, when considering recordings of complete performances.

## 6.9 Hypothesis #3 – relationship between expressivity and musical structure

Several researchers, particularly those in the field of automated MIR, have studied the problem of extracting musical structures from recorded performances using low-level features. Serra *et al.* applied time series of harmonic pitch class profiles (*chroma bins*), normalized for loudness, to problems of structural boundary detection in Beatles' songs.<sup>415</sup> Rodriguez-Lopez *et al.* had some success using melodic cues to detect segment boundaries in vocal music, but less so in instrumental works.<sup>5</sup> Extending the

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<sup>4</sup> Joan Serra and others, 'Unsupervised Detection of Music Boundaries by Time Series Structure Features', in *Proceedings of the Twenty-Sixth AAAI Conference on Artificial Intelligence* (presented at the Twenty-sixth AAAI Conference on Artificial Intelligence, Palo Alto, California: The AAAI Press, 2012), 1616.

<sup>5</sup> Marcelo Rodriguez-Lopez, Anja Volk, and Dimitrios Bountouridis, 'Multi-Strategy Segmentation of Melodies', ed. by Hsin-Min Wang, Yi-Hsuan Yang, and Jin Lee (presented at the 5th International Society for Music Information Retrieval Conference, ISMIR, 2014), 211-2.

work of Serra *et al.*, McFee and Ellis applied techniques from spectral graph theory to look for repeated melodic patterns in recordings.<sup>6</sup>

This present research attempts to validate certain prior scholarly structural analyses using performance expressivity as the main boundary criterion. Psychologists have studied the effects of emotional tension in respect of creative activities. One result is the Yerkes-Dodson law that relates tension to performance.<sup>7</sup> This is commonly represented by an inverted U-shaped graph that relates quality of performance, particularly when cognitive anxiety is low, to a function of arousal. The arousal level, in respect of the complex nature of a musical performance, would be expected to increase and abate. This serves to falsify Hypothesis #3 by showing expressivity does operate at a macro-level.

In order to test Hypothesis #3, I attempt to detect whether or not musicians deliver intensity across *macro-structures* of a performance—Rink’s ‘higher-order structures’.<sup>8</sup> This is in contrast to expressive behaviour or gestures within independent individual phrases, formal movements or between lower-level structural boundaries.

Rink proposed that

rather than musical structure prescribing what performers do, we find that what performers do has the potential to impart meaning and create structural understanding.<sup>9</sup>

It still remains to be investigated in future research whether this is true only of the macros-structures of the *Phantasy*, or twelve-tone music generally, or whether it applies more generally across the Western art canon.

### 6.9.1 Theories of the *Phantasy*

Recordings were segmented into three or four chunks of music based on the different structural theories of Polansky, Lester, Stein, and Tipton. A PAA frame size of 150

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<sup>6</sup> Brian McFee and Daniel Ellis, ‘Analyzing Song Structure with Spectral Clustering’, ed. by Hsin-Min Wang, Yi-Hsuan Yang, and Jin Lee (presented at the 5th International Society for Music Information Retrieval Conference, ISMIR, 2014), 405.

<sup>7</sup> Elizabeth Valentine, ‘The Fear of Performance’, in *Musical Performance: A Guide to Understanding*, ed. by John Rink (Cambridge University Press, 2002), 171, <https://doi.org/10.1017/CBO9780511811739.013>. See also Teigen, Karl, ‘Yerkes-Dodson: A Law for All Seasons’, *Theory & Psychology*, 4 (1994), 525–47.

<sup>8</sup> Rink, ‘The Interpretative Shaping of Music Performance Research’, 121.

<sup>9</sup> Rink, *Ibid.* 122.

characters was applied in all cases which, since there are approximately 650 beat points in the *Phantasy*, means an overall maximal data compression ratio of 23% (150/650).<sup>10</sup> Finer-grained compression would not be useful in the case of the *Phantasy* since many of Schoenberg's 'movements' consist of only a scant few bars.

The performance maps were defined for each of the four structural theories. *Saxify* analysis was repeated by comparing DMs for each structural component separately such that a separate DM was produced for each section. Prior studies of the *Phantasy* (cf. Chapter 4) have already shown that performers engage in substantially more rubato in areas of greater musical complexity where melody alone is not the 'primary expressive source'.<sup>11</sup> Since each performer is playing the same melody, we might expect differences in interpretative treatment within the more complex areas of the *Phantasy*.

However, as noted in Chapter 2, published literature on performance analysis chiefly combines only tempo measurements with dynamics on a local basis. The purpose of *Saxify* is to attempt to 'fingerprint' much larger structures for comparison, and to show how expressivity operates there. The four alternative segmentations (by Polansky, Lester, Stein and Tipton) are re-cast in Table 6.2 to show bar correspondences by section:

	A	B	C	B'	A'	A
Polansky	1-84	85-153			154-166	
Lester	1-33	34-153			154-166	
Stein <sup>12</sup>	1-31	32-84	85-134		135-166	
Tipton	1-33	34-84		85-153		154-166

Table 6.2 Bar ranges corresponding to possible structural form

It can be seen that there are several bar ranges that are agreed upon by the different scholars: Lester and Tipton agree precisely on the A section, with Stein differing by only two bars; Stein and Tipton concur almost exactly on the B section; Polansky, Lester and Tipton agree on the final section (classed as A by Tipton). Were expressivity

<sup>10</sup> Efsthatis Stamatatos and Gerhard Widmer, 'Music Performer Recognition Using an Ensemble of Simple Classifiers', *Proceedings of the 15th European Conference on Artificial Intelligence*, ed. by F Harmelen (presented at the ECAI 2002, Amsterdam: IOS Press, 2002), p. 3. Their research proposed splitting a performance into 4-5 equal length chunks without consideration as to section breaks or styles. Their work did not involve symbolic methods.

<sup>11</sup> Renee Timmers and others, 'The Influence of Musical Content on Tempo Rubato', *Journal of New Music Research*, 29.2 (2000), 131-58.

<sup>12</sup> Stein worked as Schoenberg's assistant from 1939 to the composer's death ten years later. See Mark Swed, 'Leonard Stein, 87; Schoenberg Institute Chief, Pianist, Teacher', *Los Angeles Times* (L.A., 25 June 2004) <http://articles.latimes.com/2004/jun/25/local/me-stein25>, Accessed: 30 June 2017.

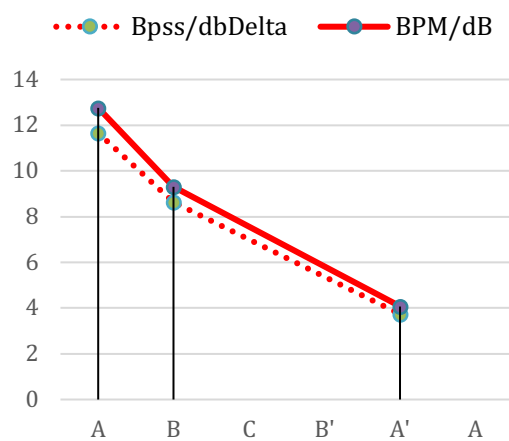
to be used by performers to communicate structural boundaries alone, one might expect to see different levels of expressivity on each side of those boundaries.

The degree of average dissimilarity is a high-level window into possible different patterns of expressivity for sections of a performance. The intention is to explore the operation of expressivity without reflecting on what is happening within individual phrases or at section boundaries. Such exploration begins with presenting an average value for each variable pair, and their combination, for each section of the work (as shown in Table 6.3 below). By using appropriate location mappings, it is feasible to conduct analysis at whatever level is desired. For present purposes, the calculations reflect the sections as proposed in Table 6.2 above. Average dissimilarities were calculated using the technique described in Section 4.13.4—the table shows the calculation of averages for each combination of variables:

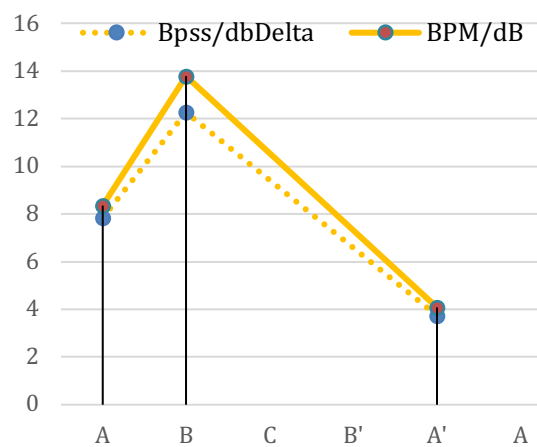
<b>Polansky</b>	<b>A</b>	<b>B</b>	<b>C</b>	<b>B'</b>	<b>A'</b>	<b>A</b>
Bpss	16.75	11.04	-	-	4.63	-
dbDelta	6.72	6.27	-	-	2.95	-
All	11.66	8.62	-	-	3.74	-
BPM	20.14	13.68	-	-	5.39	-
dB	5.52	5.01	-	-	2.85	-
All	12.76	9.31	-	-	4.08	-
<b>Lester</b>	<b>A</b>	<b>B</b>	<b>C</b>	<b>B'</b>	<b>A'</b>	<b>A</b>
Bpss	11.55	16.56	-	-	4.63	-
dbDelta	4.22	8.06	-	-	2.95	-
All	7.83	12.26	-	-	3.74	-
BPM	12.81	21.63	-	-	5.40	-
dB	3.96	6.05	-	-	2.85	-
All	8.35	13.78	-	-	4.08	-
<b>Stein</b>	<b>A</b>	<b>B</b>	<b>C</b>	<b>B'</b>	<b>A'</b>	<b>A</b>
Bpss	11.22	12.68	10.06	-	5.92	-
dbDelta	4.17	5.55	5.15	-	4.48	-
All	7.62	9.06	7.57	-	5.16	-
BPM	12.23	16.22	10.58	-	8.19	-
dB	3.84	4.21	4.02	-	3.90	-
All	8.00	10.15	7.26	-	6.00	-
<b>Tipton</b>	<b>A</b>	<b>B</b>	<b>C</b>	<b>B'</b>	<b>A'</b>	<b>A</b>
Bpss	11.55	12.33	-	11.05	-	4.63
dbDelta	4.22	5.49	-	6.27	-	2.95
All	7.83	8.85	-	8.62	-	3.74
BPM	12.81	15.78	-	13.68	-	5.40
dB	3.96	4.19	-	5.00	-	2.85
All	8.35	9.92	-	9.31	-	4.08

*Table 6.3 Pattern of average dissimilarities*

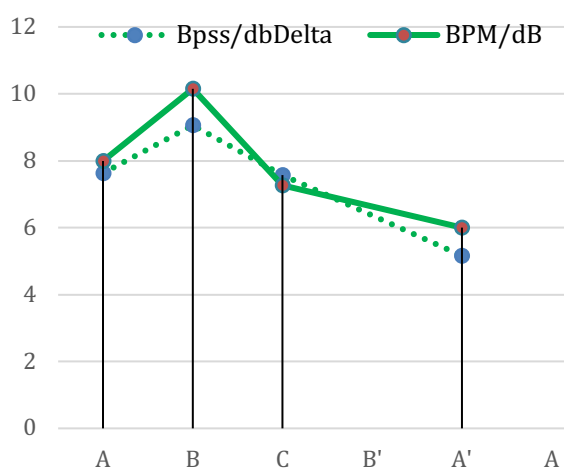
In Table 6.4 below are shown graphical representations of the ‘All’ values for each theory as extracted from Table 6.3 (it should be noted that the profiles of averages for individual variables follow very similar trajectories). The solid line in each case represents the values corresponding to the BPM/dB pair. The dotted lines represents the values corresponding to the Bpss/dbDelta pair.



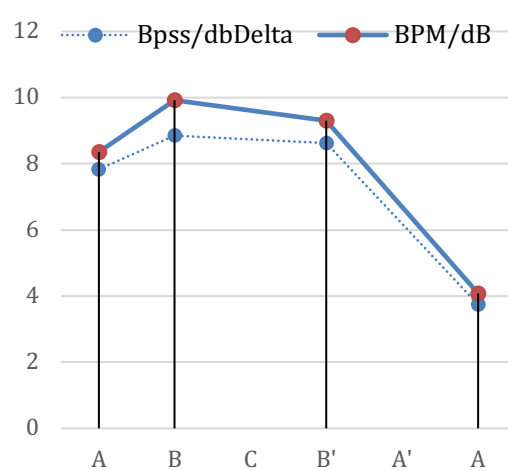
(a) Polansky



(b) Lester



(c) Stein



(d) Tipton

Table 6.4 (a)-(d) Trajectories of expressive intensity



I suggest that the above data exhibit a common *expressive trajectory* across the complete performances. In each case, and whichever pair of variables is selected, there is a surge in expressivity away from the norm typically in the B section.<sup>13</sup> The shape of the graphs is consistent for both pairings—with the exception of Polansky's which shall be explored below. In the other three cases, average intensity peaks within the second section of the work and then tapers off to final values that are universally lower than the initial starting points.

In each case, it can be seen that the general level of expressivity prolongs downwards towards the final part of each performance, no matter which structural theory is applied, and no matter which pair of variables is measured. The movement of expressivity away from that shown in the A section, then declining at the finale, is a clear indication of intensity development across a complete performance.

Polansky's A section is almost three times the length that is suggested by the other scholars. Expressivity levels, using his B and A' sections, decline immediately from the initial values without the characteristic bump shown by the other three structures. I will show that his selection of a larger, 84-bar, A section is the reason for this.

The dbDelta and bpss variables are not straightforward for a listener to detect explicitly, in the way that basic tempo or dynamics changes may. There is much more variability, throughout the body of recordings, in those variables. Yet from Table 6.4 it may be observed that both variable pairs exhibit almost identical expressivity characteristics. The clear increase and abatement of intensity represents tension and release on a structural scale. This may be contrasted with localised expressivity that delineates phrases or cadential points.

Ebb and flow of intensity was previously identified by Eitan as integrating 'various parameters (e.g., pitch contour, dynamics, textural and temporal density, or harmonic tension) followed by abatement'.<sup>14</sup> This may be associated with a progression of tension and release. Intensity in this context implies an increase (or decrease) in some bundle of parameters. Similar studies have related this characteristic to performance at a phrase

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<sup>13</sup> Langner and Goebbl found a characteristic performance "expression trajectory", in a counter-clockwise direction, when plotting BPM, on the x-axis, against loudness (albeit on a very small sample of performances). See also Jörg Langner and Werner Goebel, 'Visualizing Expressive Performance in Tempo-Loudness Space', ed. by Tim Crawford and Lorna Gibson, *Computer Music Journal*, 27 (2003), 69–83+86.

<sup>14</sup> Eitan, *Ibid.*, 149.

level but the *Saxify* results demonstrate that ebb and flow of expressivity also operates at a higher level, and across a complete performance. Previous studies have indicated a strong relationship between loudness and arousal. *Saxify* analysis of the *Phantasy* also shows the complexity of this relationship. An additional pointer to the shape of the graphs may be proposed by the aforementioned Yerkes-Dodson law to suggest that performance of a work as complex as the *Phantasy* sees the performer develop increasing levels of emotion up to peak intensity before a decline. Throughout the course of a performance, the shape of this trajectory of intensity suggests that performer arousal levels are a key factor in creative music performance, although whether this extends to other musics and other works must be the subject of further research.

### 6.9.2 Polansky's view of structure

On first studying the shape of the trajectories in Table 6.4 one might conclude that Polansky's theory provides a very different basis for evaluating expressivity compared to the results from the other three. Expressivity, viewed on the basis of his structural analysis, starts at a high level but declines from the initial value to what is almost the same endpoint as the others. There is no increase to a peak, and decline.

Polansky takes a broader view of the extent of the A section – for him it is 84 bars long. The others assume 33 or 31 bars. The 2-bar difference is a *poco meno mosso, dolce*. For Polansky, the B section follows from bars 85 to 153. The almost 50-bar difference in Polansky's A section incorporates much of the music that gives rise to the peak intensity visible from the viewpoint of the other 3 theories. These 50 bars have a significantly higher lyrical quality: starting *meno mosso, cantabile* followed by *lento*, then a *grazioso* segment before the *Piu mosso* that eventually dies away. Then a furious *accelerando* precedes what could in effect be a classical *Scherzando*. The character of what precedes them, particularly from bar 25 (*piu mosso, furioso* with *crescendo* and percussive piano chords) is so different, in both parts, from the beauty of what follows. It would seem from the part writing that the music from bars 31/33 onwards really demands that the performer heighten the intensity.

Even Lester, who prolongs the B section for the same number of bars as Polansky, ends up with very much the same shape as Stein and Tipton. It seems as if the assumption of a longer A section is what causes Polansky's significant difference from the other scholars, even though all four finish in a similar place during the final 10-20 bars. This

longer A section also has the effect of starting at a higher level of intensity since it includes the bars up to 84 in its averaging calculation.

### 6.9.3 Hypothesis falsified

The evidence is sufficient to falsify the third hypothesis—it may be concluded that performances do exhibit ebb and flow intensity characteristics when viewed across a complete performance, and independently of more localised expressivity applied by a performer. It has been demonstrated how Polansky's selection of a longer A section, that includes the bars that demand most expressivity, has the effect of hiding the *ebb and flow*. Accordingly, it would seem that the other theories are better representations of musical structure at this level, even if they differ in some respects, and at least in the most likely pattern of intensity that is communicated to listeners.

### 6.10 Chapter summary

The *Phantasy's* earliest performers were musicians associated closely with Schoenberg (e.g. Varga, Kolisch and Koldofsky). These earliest performers applied a greater degree of expressive flexibility in performance with respect to expressivity. Over time, performances have become more alike.

The experiments were designed to explore the nature of expressivity as executed on a structural level. Results demonstrate that performers differentiate sections of the *Phantasy* by altering the average level of intensity. The general tendency is to increase the level after an initial structural boundary, and then gradually reduce the average expressivity in the final parts of each performance. There is a direct relationship between the nature of the scoring and the trajectory of intensity. In the case of the *Phantasy* it would seem that the more melodious part of the music is where the performers average the highest levels of peak intensity. This remains to be tested on other types of music but perhaps is not an unsurprising finding.

Raffman is correct in proposing that a large proportion of the listening public undoubtedly dislikes twelve-tone music and glimpses no useful structures within it. She supports Taruskin in seeing no role whatever for expressive gestures in such music. Her active dislike ignores how performers relate to this type of music and the expressive intent that they bring to their performances. Initial audience reactions, particularly one-time ones, should not be relied upon as conclusive evidence of defects in serialism

generally nor in dodecaphonic styles. In using sonic information contained within recordings it is possible (as in Table 6.5 above) to see that performers do relate intensity of expression to some higher-level comprehension of musical structure.

On the evidence of performances of the *Phantasy*, a work that certainly has engaged performers, this dissertation has demonstrated similarities in how they delimit larger musical structures and in concentrating energy to deliver peak intensities. There are differences between how different structural views of the work affect insights into the patterns of intensity. But it is undoubtedly the case that the similarity in overall trajectories is more significant than individual differences.

## CHAPTER 7 | SYNTHESIS - CONCLUDING DISCUSSION

In light of the experimental results in Chapter 6, this chapter discusses the pros and cons of the *Saxify* model. It also makes recommendations for extending the model and pursuing related MPS research, accepting that there are limitations to any model that need resolution.

I consider that this dissertation presents significant achievements in music performance science. It is the first time, to my knowledge, that the SAX technique has been applied to music recordings analysis and with proven value. In addition to the suggested pedagogical value, this may, and should, lead to advances in recording identification, performer matching and fraud detection. It provides insights into how performers shape music and how structures are identified and communicated to listeners. It points the way towards future research that can identify other parameters of expressive performance and to incorporate them in the analysis. I hope to be part of that research. Studying the Schoenberg *Phantasy* proved hugely satisfying not least because I identified that the rhythmic values of the opening motifs are the Morse Code symbols for ‘AS’.

*Saxify* has been shown to be capable of providing unique *performance fingerprints* that can augment an analysis of recorded musical performances. It classifies performances, in respect of variability from a PN.<sup>1</sup> It facilitates multivariate comparisons such that salient performance variable(s) can be identified and drilled-down for detail.

Importantly, it achieves these results working with compressed data (see §2.4 above) rather than all of the data from each performance. This is not necessarily important in considering a work as short as the *Phantasy*: benefits will accrue when analyzing larger, more complex ones. It also provides a way of comparing performances of different parts of a work. This is an important aid to understanding how performers deliver expressive shape to a work by altering timings and rhythms in different parts of a performance.

Specifically, I have shown how to develop an intensity map for a performance (based on *performance fingerprints*) and then to develop a metric to relate the intensity map to other performances of the same work. By applying this metric to sections of

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<sup>1</sup> Given that the *Phantasy* performances provide reasonably large datasets, it is possible to rely on the Central Limit Theorem to make statements about the significance of experimental results. Weisstein, <http://mathworld.wolfram.com/CentralLimitTheorem.html>, Accessed: 3 January 2015.

performances from different dates, it is possible to show the extent to which performance style (in terms of expressivity) mirrors highest-level musical structures.

An important overall conclusion is that there is a remarkable similarity across the majority of performances that were researched in how the intensity of expression increases to a peak and then tapers off towards a finale. This is true of the combined as well as separate variables and is largely independent of which theoretical structure is applied to the music. The suggestion that the Yerkes-Dodson law is exhibited by music performance intensity supports the suggestions of arched convex shaping already referenced in §6.9 as well as the concept of ‘affective acceleration’ in §1.8.

An additional conclusion of the research programme is that performances of the *Phantasy* were more exploratory and innovative from the middle of the twentieth century, at least until the 1966 recording by Kolisch and Johanssen. This is demonstrated by the reduction in variability from the norm, which is particularly noticeable from 1980 onwards, irrespective of the expressive parameters used. Less extremes of rates of change of tempi and dynamics suggest a gradual lessening of innovation in expressivity. It is equally possible that repeated listening and repeated performances have resulted in some degree of consensus as to how this music should be delivered. I suggested in §1.9.28 that reduced variability in the later period may be interpreted as simplification of the message in order to communicate more clearly. In general, the research progressed satisfactorily and there were very few recordings that could not be obtained. One aspect of the data collection process that was troublesome to deal with was variability in creating accurate tap tracks. It was very important to get this to be as accurate as possible, since all subsequent measurements depend on beat locations. The process of listening to the music and identifying beats is not an easy one: (1) initial taps typically lag actual beat onsets by 60-80ms thus highlighting the importance of repeated listening and of using software to adjust the tapped beat onsets (usually to no more than 10ms variance from actual). Fatigue became a serious factor in extending the time required to complete this early part of the research; (2) automated beat identification software, as in the Queen Mary VAMP plugins, is improving but is still limited in its application to changing time-signatures and metres.

## 7.1 Context

This dissertation has reviewed the variety of scholarly research and key theories that inform my research, including cross-disciplinary studies and innovative technical methods. It relies very much upon the ontological argument that musical performances are art. Music recordings do pose challenges as research sources. There is no extended formal analysis of the *Phantasy* within this thesis. Its musical structures have been proposed in four principal scholarly studies that are used to show how expressive playing communicates to listeners.

The *Saxify* performance analysis model relies substantially upon data science techniques to analyse music data derived from recordings. The model is intended to be generally applicable to music performances using multiple performance variables captured over time and treated as time-series. It captures measurements at fixed intervals, converts those to a symbolic representation (which inherently provides data compression), generates a performance norm (a conceptual average of a set of performances), and quantifies dissimilarity between each performance, the other performances, and the norm.

The dissimilarity measure of a performance from the norm is its *performance fingerprint*. I validated *Saxify* against Chopin Mazurka data that was previously published by researchers at CHARM. Based on successful validation of the overall approach, I evaluated experimental results from recordings of Schoenberg's *Phantasy*.

## 7.2 Individual approaches

A performance, even within an ensemble, necessitates individual and personal treatment of music. It is never so much a rigid mapping of thought, or score, to performance as it is a personalisation of intensity and of how to shape and communicate structures to listeners. There seems little doubt that expressivity operates on multiple levels that: (1) shape individual notes, bars and phrases, and (2) reflect a performer's engagement across a work as a whole.

An important question is whether it is possible to generalise from specific results. Apart from the validation of the approach against the Cook-Sapp published data, my analysis of Schoenberg's *Phantasy* has demonstrated that quantitative statements as to performance dissimilarities are a valid tool of performance analysis. There are infinite

ways of shading individual parts of a performance and of distinguishing any musician from others on the basis of performance styles. However, in the absence of measurement, it is difficult to formulate an objective way of evaluating distinctions. Providing a measurement model is a significant achievement even if further research is required to establish whether the model is more generally applicable across different types of music and with a wider array of measurable variables.

I propose that music performance research may be of value to early-stage musicians. It is difficult to cope with the many aspects of learning a musical instrument and subsequently to develop higher levels of expertise. Inexperienced musicians need guidance on the tiny window into a composer's mind which is represented by a score, whereas experience hopefully brings a far larger set of aesthetic and cultural ideas to bear. Useful as the technical skills are, they cannot substitute for a vision of musical structure. My ambition here is to provide some limited guidance as to how musicians might think about the higher levels of expressive delivery. This should be done in conjunction with analysis of structure to help with the communication through performance. However parallel development of analytical skills is needed since it is difficult to learn and differentiate the *how* of performance from the *what* of a particular piece of music at hand.

### **7.3 Limitations of data management**

Ideally, however, the initial calculations should all be done in one place. Microsoft Excel has the great benefits of usability and ease of data manipulation. However, it is not suited to either storing or processing very large amounts of data quickly. It is recommended that improvements be made to the fundamental data management design (replacing Excel with a suitable, possibly portable, database management system). It is also recommended to extend the range of possible input/output formats particularly in light of the types of future data variables noted in §7.5 below.

### **7.4 Limitation of the software language**

*Saxify* software components were transposed to the statistical programming language R from an initial implementation in Java because the latter was found to be both more verbose and slower in performance. R offers significant advantages in native vector-



processing features. Further research in this area is needed to guarantee processing speed advantages for much larger volumes of music data.

## 7.5 Recommendations for future research

There are alternative measures of dissimilarity that might be considered in the interests of processing speed. Levenshtein Distance (String Edit Distance) is one such example. Additional music performance variables need to be considered for inclusion in the *performance fingerprints*, so long as they can be measured. It is important to conduct experiments using small numbers of such variables in order to reduce the likelihood of attaining spurious results in high-dimension data. Candidate variables include, but are not limited to:

- expressive intonation
- articulation
- vibrato width and frequency
- harmonic components of tones

An extended analysis could look into divergences from a score by creating a *score norm* against which to base comparisons. It is beyond the scope of the present research to extend the *Saxify* analytical model to incorporate a *score norm* in addition to a *performance norm*. The purpose of such an extension could be to provide insights into how performances diverge from the composer's original intent, assuming the score represents that intent in full. Divergence could indicate changing attitudes to the importance of a physical score. Here are some recommendations for creating a *score norm* using only the score as the basis to consider:

- establishing sectional tempi based on metronome markings;
- a systematic way to implement measurement of macro tempo indications throughout the score (e.g. *adagio*, *allegro*, etc.);
- how to implement other indications (e.g. *con fuoco*, *ritenuto*, etc.)
- coding dynamics markings on a scale – perhaps the range pppp to ffff on a 1-100 scale that could be mapped to dB<sub>spl</sub> range with *piano* in a normal room benchmarked at 50;
- how to implement 'dynamic change curves' to allow for rates of change within

*crescendi, decrescendi*, and various type of emphasis (e.g. *sF*, *Subito piano*, *staccato*, etc.);

- how to treat instrument-specific requirements such as those of percussion.

If the above items were to be resolved satisfactorily, a *score norm* (SN) could be established using similar principles to the *performance norm*. Each performance could then be compared against the SN to produce a score-based distance matrix. Such comparisons will help in evaluating how far performances deviate from the notated score and provide measures of expressivity as deviations from it. This also raises an issue of considering the ground truth and editorial choices made on alternative scores.

An additional requirement is for the software programs to be immediately usable by all MPS researchers, irrespective of coding abilities. As noted in the Introduction, the code is published on Github in the hope it can attract research collaborators to improve it.

Limitations arise at present from a need to understand the mathematical basis for the *Saxify* tool, and the need to further customise and develop the software to make it easy to use for researchers. It would be admirable if the tool were developed to the point where its entire functionality was capable of being specified in parameters set from outside the program. For the present, and although stable, the software must be modified in order to add new variables whereas the number of variables should properly be a parameter of the model. It is to be recognised that adding too many variables and extending the dimensionality could lead to spurious results and correlations.

Further research is also needed to encapsulate all the ideal functionality and to develop a suitable graphical interface. The ultimate goal should be to provide the front-end functionality on a mobile device (such as a tablet) with back-end processing performed in the Cloud given the practically unlimited computer power available there. This would have an additional advantage of facilitating sharing both data, code and results between music performance researchers. Given the power of Android tablets, R can already run within an app (GNUroot Debian) to mimic Linux hosting on Android.<sup>2</sup> More research is needed to develop a suitable data representation for such an environment, embed the *Saxify* code on a mobile device, explore automated interfaces to collect data, and

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<sup>2</sup> At <https://selbydavid.com/2017/12/29/r-android/>, Accessed: 10 January 2019.

provide tools to measure and to visualize results that go beyond clustering diagrams. Such a progression could boost field research on recordings and on live performances assuming appropriate copyright permissions were put in place.

I finish with the words of Zohar Eitan whose many research publications on music performance provoked me to develop a reliable way to measure and discriminate musical intensity. This dissertation is a direct response to his call for controlled, appropriate empirical methods in music performance research:

Shaping musical intensity (energy) in time is what performers do. Controlled empirical methods will enable us to understand better how performers associate different musical dimensions in their search of appropriate intensity levels and shapes.<sup>3</sup>

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<sup>3</sup> Eitan, *Ibid.*, p. 158.

# Bibliography

- Abramowitz, Milton, 'Elementary Analytical Methods', in *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables*, ed. by Milton Abramowitz and Irene Stegun, 1972nd, 10th printing with corrections edn (Washington: Dept of Commerce (National Bureau of Standards), 1964), 9–64
- Addis, Laird, *Of Mind and Music* (Ithaca: Cornell Press, 1999)
- Adomavicius, Gediminas, Alexander Tuzhilin, 'Toward the Next Generation of Recommender Systems: A Survey of the State-of-the-Art and Possible Extensions', *IEEE Transactions on Knowledge and Data Engineering*, 17 (2005), 734–49
- Adorno, Theodor, *Essays on Music*, ed. by Richard Leppert, trans. by Susan Gillespie (Berkeley: University of California Press, 2002)
- — —, 'On the Problem of Musical Analysis', trans. by Max Paddison, *Music Analysis*, 1 (1982), 169–87
- — —, *Quasi Una Fantasia: Essays on Modern Music*, trans. by Rodney Livingstone (London & New York: Verso Classics, 1994)
- Adorno, Theodor, Anne Mitchell, Wesley Blomster, *Philosophy of Modern Music*, Athlone Contemporary European Thinkers (New York: Continuum, 2003)
- Aggarwal, Charu, *Outlier Analysis* (New York: Springer Science, 2013)
- Agon, Carlos, 'OpenMusic: un langage visuel pour la composition musicale assistée par ordinateur' (Doctoral dissertation, Université de Paris VI, 1998)
- Almansa, Josué Pedro Delicado, 'Analysing Musical Performance through Functional Data Analysis: Rhythmic Structure in Schumann's *Träumerei*', *Connection Science*, 21 (2009), 207–25
- Anderson, John, James Greeno, Lynne Reder, and Simon, Herbert. 'Perspectives on Learning, Thinking, and Activity', *Educational Researcher*, 29 (1999), 11–13
- Andreatta, Moreno, 'Mathematica est exercitium musicae: la recherche mathémusicale et ses interactions avec les autres disciplines' (Habilitation Dissertation, University of Strasbourg, 2010), <https://tel.archives-ouvertes.fr/tel-00526432/document>
- Arnone, Augustus, 'The Aesthetics of Textural Ambiguity: Brahms and the Changing Piano', *Current Musicology*, 82 (2006)
- Ashby, Arved, 'Schoenberg, Boulez, and Twelve-Tone Composition as "Ideal Type"', *Journal of the American Musicological Society*, 54 (2001), 585–625
- Askenfelt, Anders, 'Measurement of Bow Motion and Bow Force in Violin Playing', *The Journal of the Acoustical Society of America*, 80 (1986), 1007–15

- Asmus, Edward, 'The Measurement of Musical Expression' (presented at the Suncoast Music Education Research Symposium, Tampa, Florida, 2009)
- Atkin, Albert, *Peirce* (Oxford: Routledge, 2016)
- Audacity Team, *Audacity*, 2013, <http://audacity.sourceforge.net/>, Accessed: 1 January 2013.
- Auner, Joseph, *A Schoenberg Reader* (Yale University Press, 2003)
- Babbitt, Milton, 'My Vienna Triangle', in *Collected Essays of Milton Babbitt*, ed. by Stephen Peles, Stephen Dembski, Andrew Mead, and Joseph Straus (Princeton NJ: Princeton University Press, 2003), 466–88
- — —, 'Responses: A First Approximation', *Perspectives of New Music*, 14 no. 2/ 15 no. 1 (1976), 3–23
- — —, 'Who Cares If You Listen', *High Fidelity*, 1958
- Baker, Christian, 'The Influence of Violin Schools on Prominent Violinists/Teachers in the United States' (Doctor of Music dissertation, 2005)
- Banchhor, Sumit, Arif Khan, A 'Musical Instrument Recognition Using Zero Crossing Rate and Short-Time Energy', *International Journal of Applied Information Systems*, 1 (2012), 1–4
- Bangert, Daniel and Emery Schubert, Dorottya Fabian, 'A Spiral Model of Musical Decision-Making', ed. by Aaron Williamon, *Frontiers in Psychology*, 5 (2014), 1–11, <https://doi.org/10.3389/fpsyg.2014.00320>
- Barolsky, Daniel, 'The Performer as Analyst', *Music Theory Online*, 13 (2007)
- Barthet, Mathieu, Richard Kronland-Martinet, Sølvi Ystad, 'Consistency of Timbre Patterns in Expressive Music Performance', in *Proc. of the 9th Int. Conference on Digital Audio Effects (DAFx-06)*, (presented at the 9th Int. Conference on Digital Audio Effects (DAFx-06), Montreal, 2006)
- Baur, Dominikus, Jennifer Büttgen, Andreas Butz, 'Listening Factors: A Large-Scale Principal Components Analysis of Long-Term Music Listening Histories' (presented at the CHI'12, Austin: ACM, 2012), 1273–76
- Bengtsson Ingmar, Alf Gabrielsson, 'Methods for Analyzing Performance of Musical Rhythm', *Scandinavian Journal of Psychology*, 21 (1980), 257–68
- Benjamin, Walter, 'The Work of Art in The Age of Mechanical Reproduction', in *Technology and Culture, the Film Reader*, ed. by Andrew Utterson (Oxford: Routledge, 2005)
- Beran, Jan, *Statistics in Musicology* (Boca Raton: CRC Press, 2003)
- Beran, Jan, Guerino Mazzola, 'Analyzing Musical Structure and Performance—A Statistical Approach', *Statistical Science*, 14 (1999), 47–79
- Bernays, Michel, Caroline Traube, 'Verbal Expression of Piano Timbre' (presented at the International Symposium on Performance Science 2011, Toronto, Canada, 2011), 299–304
- Berry, Wallace, *Structural Functions in Music* (Englewood Cliffs, N.J.: Prentice-Hall, 1976)

- Best, Stephen, Douglas Kellner, *Postmodern Theory: Critical Interrogations* (New York: Guilford, 1991)
- Blank, Martin, Jane Davidson, 'An Exploration of the Effects of Musical and Social Factors in Piano Duo Collaborations', *Psychology of Music*, 35 (2007), 231–48
- Bloomfield, Peter, *Fourier Analysis of Time Series* (New York: John Wiley & Sons, 2000)
- Borg, Ingwer, Patrick Groenen, *Modern Multidimensional Scaling: Theory and Applications*, 2nd edn (Springer Science, 2005)
- Borio, Gianmario, 'Work Structure and Musical Representation: Reflections on Adorno's Analyses for Interpretation', trans. by Martin Iddon, *Contemporary Music Review*, 26 (2007), 53–75
- Boss, Jack, 'Schoenberg's Op. 22 Radio Talk and Developing Variation in Atonal Music', *Music Theory Spectrum*, 14 (1992), 125–49
- — —, *Schoenberg's Twelve-Tone Music: Symmetry and the Musical Idea* (Cambridge: Cambridge University Press, 2014)
- Botstein, Leon, 'Music and the Critique of Culture: Arnold Schoenberg, Heinrich Schenker, and the Emergence of Modernism in Fin de Siècle Vienna', in *Constructive Dissonance: Arnold Schoenberg and the Transformations of Twentieth-Century Culture*, ed. by Juliane Brand and Christopher Hailey (Berkeley: University of California Press, 1997), 3–22
- Boulez, Pierre, 'Schoenberg Is "Dead"', in *Notes of an Apprenticeship*, trans. by Herbert Weinstock (New York: Alfred A. Knoff, 1968), 268–75
- Bowen, Jose, 'Bibliography of Performance Analysis', <http://www.http://josebowen.com/bibliography-of-performance-analysis/>, Accessed: 11 February 2011
- — —, 'Performance Practice Versus Performance Analysis: Why Should Performers Study Performance', *Performance Practice Review*, 9 (1996), 16–35
- Bowen, José, 'Tempo, Duration and Flexibility: Techniques in the Analysis of Performance', *Journal of Musicological Research*, 16 (1996), 111–56
- — —, 'The History of Remembered Innovation: Tradition and Its Role in the Relationship between Musical Works and Their Performances', *The Journal of Musicology*, 11 (1993), 139–73
- Brahms, Johannes, *Intermezzo Op.10 No.4*, ed. by Rafael Joseffy (Philadelphia: Oliver Ditson, 1910), [http://imslp.org/wiki/4\\_Ballades,\\_Op.10\\_%28Brahms,\\_Johannes%29](http://imslp.org/wiki/4_Ballades,_Op.10_%28Brahms,_Johannes%29), Accessed: 4 January 2015
- Bresin, Roberto, 'What Is the Color of That Music Performance?' (presented at the International Computer Music Conference, Barcelona: International Computer Music Association, 2005)
- Brodie, Michael, 'The Scope of Data Science', Email communication, 25 July 2017
- Brown, Stephen, 'The "Musilanguage" Model of Music Evolution', in *The Origins of Music*, ed. by Nils Wallin, Björn Merker, and Stephen Brown (Boston: MIT Press, 2000), 271–300
- Buck, Bryony, Jennifer MacRitchie, Nicholas Bailey, 'The Interpretative Shaping of Embodied Musical Structure in Piano Performance', *Empirical Musicology Review*, 8 (2013), 92–119

- Bujic, Bojan, *Arnold Schoenberg* (London: Phaidon Press, 2011)
- Butler, Matthew, Dimitar Kazakov ‘Creating a Level Playing Field for All Symbols in a Discretization’, *ArXiv Preprint ArXiv:1210.5118*, 2012, 1–14
- Byron, Avior, ‘Pierrot Lunaire in Studio and Broadcast: Sprechstimme, Tempo and Character’, *Journal for the Society for Musicology in Ireland*, 2 (2006), 69–91
- Calle, Eduardo, ‘Music as a Branch of Mathematics: 2007 Winter Institute’ (Miami Dade College, 2007)
- Cammurri, Antonio, Matteo Ricchetti, Riccardo Trocca, Gualtiero Volpe, ‘EyesWeb - Toward Gesture and Affect Recognition in Interactive Dance and Music Systems’, *Computer Music Journal*, 24 (2000), 57–59
- Canadian Broadcasting Corporation, *Menuhin and Gould in Conversation about Schoenberg*, <https://www.youtube.com/watch?v=av2XTNgA72w>, Accessed: 13 June 2013
- Canazza, Sergio, Giovanni de Poli, Carlo Drioli, Antonio Roda, Alvise Vidolin, ‘Modeling and Control of Expressiveness in Music Performance’, *Proc IEEE*, 92 (2004), 686–701
- Canazza, Sergio, Carlo Drioli, Antonio Roda, Alvise Vidolin, ‘Expressiveness in Music Performance: Analysis, Models, Mapping, Encoding’, in *Structuring Music through Markup Languages: Designs and Architectures*, ed. by Jacques Steyn (Hershey PA: IGI Global, 2013), 156–86
- Cannam, Chris, Christian Landone, Mark Sandler, ‘Sonic Visualiser: An Open Source Application for Viewing, Analysing, and Annotating Music Audio Files’, in *Proceedings of the ACM Multimedia 2010 International Conference* (presented at the ACM Multimedia 2010 International Conference, New York: ACM, 2010)
- Chai, Wei, Barry Vercoe, ‘Structural Analysis of Musical Signals for Indexing and Thumbnailing’, in *Proceedings of the 3rd ACM/IEEE-CS Joint Conference on Digital Libraries* (presented at the JCDL 03, Washington: IEEE Computer Society, 2003), 27–34
- Chan, Apple, ‘*Introduction to Sound: Manipulation with Decibels*’, 2008, <http://personal.cityu.edu.hk/~bsapplec/manipula.htm>, Accessed: 25 June 2016
- Cherlin, Michael, *Schoenberg’s Musical Imagination* (Cambridge: Cambridge University Press, 2007)
- Chomsky, Noam, *Aspects of the theory of syntax*, (Cambridge MA: MIT Press, 1965)
- Clarke, Eric, ‘Commentary on Huovinen’s “Varieties of Musicological Empiricism”’, *Empirical Musicology Review*, 1 (2006), 28–32
- — —, ‘Empirical Methods in the Study of Performance’, in *Empirical Musicology: Aims, Methods, Prospects*, ed. by Eric Clarke and Nicholas Cook (Oxford: OUP, 2004), 77–102
- — —, ‘Expression in Performance’, in *The Practice of Performance: Studies in Musical Interpretation*, ed. by John Rink (Cambridge: CUP, 1995)
- — —, ‘Generative Principles in Music Performance’, in *Generative Processes in Music*, ed. by John Sloboda (Oxford: Clarendon Press, 1988), 1–26

- — —, 'Listening to Performance', in *Musical Performance: A Guide to Understanding*, ed. by John Rink (Cambridge: CUP, 2002)
- — —, 'Mind the Gap: Formal Structures and Psychological Processes in Music', *Contemporary Music Review*, 3 (1989), 1–13
- — —, 'Some Aspects of Rhythm and Expression in Performances of Eric Satie's "Gnossienne No. 5"', *Music Perception*, 2 (1985), 299–328
- — —, 'Structure and Expression in Rhythmic Performance', in *Musical Structure and Cognition*, ed. by Peter Howell, Ian Cross, and Robert West (Academic Press: London, 1983), 209–36
- — —, 'The Impact of Recording on Listening', *Twentieth-Century Music*, 4 (2007), 47–70
- — —, 'Timing in the Performance of Erik Satie's "Vexations"', *Acta Psychologica*, 50 (1982), 1–19
- Clynes, 'Microstructural Music Linguistics', *Cognition*, 1995, 269–310
- Clynes, Manfred, 'Expressive Microstructure in Music, Linked to Living Qualities', *Studies of Music Performance* (Stockholm: Royal Swedish Academy of Music, 1983)
- — —, 'Generative Principles of Musical Thought: Integration of Microstructure with Structure', *Communication and Cognition AI*, 3 (1986), 185–223
- — —, 'Sources of Musical Meaning Tests of Composer's Pulses', in *Proceedings of the First International Conference on Music Perception and Cognition* (presented at the First International Conference on Music Perception and Cognition, Kyoyo, 1989), 383–88
- — —, 'What Can a Musician Learn about Music Performance from Newly Discovered Microstructure Principles (PM and PAS)?', in *Action and Perception in Rhythm and Music* (Stockholm: Royal Swedish Academy of Music, 1987), 201–33
- Cochrane, Tom, Olivier Rosset, 'Expressive Dimensions in Music', in *Proceedings of CMMR 2012* (presented at the 9th International Symposium on Computer Music Modelling and Retrieval, Queen Mary University, London, 2012), 20–28
- Cohen, Joel, 'Information Theory and Music', *Behavioral Science*, 7 (1962), 137–63
- Cook, Nicholas, *Beyond the Score: Music as Performance* (Oxford: Oxford University Press, 2013)
- — —, 'Border Crossings: A Commentary on Henkjan Honing's "On the Growing Role of Observation, Formalization and Experimental Method in Musicology"', *Empirical Musicology Review*, 1 (2006), 7–11
- — —, 'Bridging the Unbridgeable? Empirical Musicology and Interdisciplinary Performance Studies', in *Taking It to the Bridge: Music as Performance*, ed. by Nicholas Cook and Richard Pettengill (Ann Arbor: Michigan University Press, 2013)
- — —, 'Changing the Musical Object: Approaches to Performance Analysis', in *Music's Intellectual History: Founders, Followers, and Fads* (New York: RILM, 2009), 775–90



- — —, 'Implications for Music Studies', in *Expressiveness in Music Performance: Empirical Approaches across Styles and Cultures*, ed. by Dorottya Fabian, Renee Timmers, and Emery Schubert (Oxford: OUP, 2014), 331–34
- — —, 'Looking Back at CHARM', *Charm Newsletter* (London, 2009), Nicholas Cook edition, 1–2
- — —, 'Methods for Analysing Recordings', in *The Cambridge Companion to Recorded Music*, ed. by Nicholas Cook, Eric Clarke, Daniel Leech-Wilkinson, and John Rink (Cambridge: Cambridge University Press, 2009), 221–45
- — —, *Music, Imagination, and Culture* (Oxford: OUP, 1990)
- — —, 'Perception: A Perspective from Music Theory', in *Musical Perceptions*, ed. by Rita Aiello and John Sloboda (New York: Oxford University Press, 1994)
- — —, 'Performance Analysis and Chopin's Mazurkas', *Musicae Scientiae*, XI (2007), 183–207
- — —, *The Schenker Project: Culture, Race, and Music Theory in Fin-de-Siecle Vienna* (New York: Oxford University Press, 2007)
- Cook, Nicholas, Eric Clarke, 'What Is Empirical Musicology', in *Empirical Musicology: Aims, Methods, Prospects*, ed. by Cook Nicholas and Clarke Eric (New York: OUP, 2004), 3–14
- Cook, Nicholas, Craig Sapp, 'Une Pure Coïncidence? Joyce Hatto et Les Mazurkas de Chopin', trans. by Jean-François Cornu, *L'étincelle: Le Journal de La Création à l'IRCAM*, 3 (2008), 19–21
- Cooper, David, Ian Sappiro, 'Ethnomusicology in the Laboratory: From the Tonometer to the Digital Melograph', *Ethnomusicology Forum*, 15 (2006), 301–13
- Cope, David, *Computers and Musical Style* (Madison, Wisconsin: A-R Editions, 1991)
- Cott, John, *Conversations with Glenn Gould* (Chicago: University of Chicago Press, 1984)
- Covach, John, 'Dahlhaus, Schoenberg and the New Music', *In Theory Only*, 12 (1991), 19–42
- — —, 'The Sources of Schoenberg's "Aesthetic Theology"', *19th-Century Music*, 19 (1996), 252–62
- — —, 'Twelve-Tone Theory', in *The Cambridge History of Western Music Theory* (Cambridge: CUP, 2002), 602–27
- Cramer, Alfred, 'The Schoenberg Circle's Utopian Performance Practice' (presented at the Annual Meeting of the American Musicological Society, Baltimore, Maryland, 1996)
- Crawford, Dorothy, 'Arnold Schoenberg in Los Angeles', *The Musical Quarterly*, 86 (2002), 6–48
- Creech, Andrea, Ioulia Papageorgi, Graham Welch, 'Concepts of Ideal Musicians', *Musical Perspectives: Journal of Research in Musical Performance*, Fall 2010 (2010)
- Culpepper, Sarah, 'Musical Time and Information Theory Entropy' (Master of Arts dissertation, University of Iowa, 2010)
- Cunningham, Pdraig and Sarah Delany, *K-Nearest Neighbour Classifiers* (Dublin: UCD, 2007)

- Dahlhaus, Carl, *Aesthetics of Music*, trans. by William Austin (Cambridge: Cambridge University Press, 1982)
- — —, *Schoenberg and the New Music*, (Cambridge: University of Cambridge, 1987),  
[http://books.google.ie/books?id=7HxVu2J7Z94C&printsec=frontcover&dq=schoenberg&hl=en&ei=oJsYTd7UAYuxhQferJ24Dg&sa=X&oi=book\\_result&ct=result&resnum=3&ved=0CDEQ6AEwAjgK#v=onepage&q&f=false](http://books.google.ie/books?id=7HxVu2J7Z94C&printsec=frontcover&dq=schoenberg&hl=en&ei=oJsYTd7UAYuxhQferJ24Dg&sa=X&oi=book_result&ct=result&resnum=3&ved=0CDEQ6AEwAjgK#v=onepage&q&f=false)
- Danuser, Hermann, 'Execution, Interpretation, Performance: The History of a Terminological Conflict', in *Experimental Affinities in Music*, ed. by Paolo DeAssis (Leuven: Leuven University Press, 2016)
- Davidson, Jane, James Good, 'Social and Musical Co-Ordination between Members of a String Quartet: An Exploratory Study', *Psychology of Music*, 30 (2002), 186–201
- Daykin, Norma, 'Disruption, Dissonance and Embodiment: Creativity, Health and Risk in Music Narratives', *Health*, 9 (2005), 67–87
- Daynes, Helen, 'Listeners' Perceptual and Emotional Responses to Tonal and Atonal Music', *Psychology of Music*, 39 (2010), 468–502
- Dean, Roger, Freya Bailes, 'Time Series Analysis as a Method to Examine Acoustical Influences on Real-Time Perception of Music', *Empirical Musicology Review*, 5 (2010), 152–75
- DeNora, Tia, *After Adorno: Rethinking Music Sociology* (Cambridge: Cambridge University Press, 2003)
- — —, *Music in Everyday Life* (Cambridge: Cambridge University Press, 2000)
- — —, 'Musical Patronage and Social Change in Beethoven's Vienna', *American Journal of Sociology*, 97 (1991), 310–46
- — —, 'Musical Patronage and Social Change in Beethoven's Vienna', *American Journal of Sociology*, 97 (1991), 310–46
- Desain, Peter, Henkjan Honing, 'Tempo Curves Considered Harmful', *Contemporary Music Review*, 7 (1993), 123–38
- Devaney, Johanna, Michael Mandel, Daniel Ellis, Ichiro Fujinaga, 'Automatically Extracting Performance Data from Recordings of Trained Singers', *Psycomusicology: Music, Mind and Brain*, 21 (2011), 108–36, <https://doi.org/10.1037/h0094008>
- Dixon, Simon, *BeatRoot Vamp Plugin: Interactive Beat Tracking and Visualisation System*, 2011,  
<http://www.eecs.qmul.ac.uk/~simond/beatroot/>, Accessed: 15 June 2014
- — —, 'On the Analysis of Musical Expression in Audio Signals', in *Proceedings of the Conference on Storage and Retrieval for Media Databases 2003*, SPIE and IS&T 15th Annual Symposium on Electronic Imaging, Santa Clara CA, 122–132.
- Dixon, Simon, Werner Goebel, Gerhard Widmer, 'The Performance Worm: Real Time Visualisation of Expression Based on Langner's Tempo-Loudness Animation', in *Proceedings of the International Computer Music Conference* (Göteborg, 2002)

- Dodson, Alan, 'Solutions to the "Great Nineteenth-Century Rhythm Problem" in Horowitz's Recording of the Theme from Schumann's Kreisleriana, Op. 16, No. 2', *Music Theory Online (MTO)*, 18 (2012)
- Dogantan-Dack, Mine, 'Artistic Research in Classical Music Performance: Truth and Politics', in *Proceedings of the 8th Symposium on Systems Research in the Arts* (presented at the 8th Symposium on Systems Research in the Arts, London, 2006), 27–40
- — —, 'Models and Metaphors: Exploring Musical Performance', in *Systems Research in the Arts* (Baden-Baden: International Institute for Advanced Studies, 2006), 83–91
- — —, 'The Art of Research in Live Music Performance', *Music Performance Review*, 5 (2012), 34–48
- Draper, Paul, Stephen Emmerson, 'Remixing Modernism: Re-Imagining the Music of Berg, Schoenberg and Bartok in Our Time', *Journal on the Art of Record Production*, 05 (2011)
- Dreyfus, Herbert, Sean Kelly, *All Things Shining* (New York: Simon and Schuster, 2011)
- DuBiel, Joseph, 'What's the Use of the Twelve-Tone System?', *Perspectives of New Music*, 35 (1997), 33–51
- Dubnov, Shlomo, Gerard Assayag, Olivier Lartillot, Gill Bejerano, 'Using Machine-Learning Methods for Musical Style Modeling', *Computer*, 36 (2003), 73–80
- Dudeque, Norton, *Music Theory and Analysis in the Writings of Arnold Schoenberg (1874-1951)* (Aldershot: Ashgate Publishing, 2005)
- Dunsby, Jonathan, 'Performance and Analysis of Music', *Music Analysis*, 8 (1989), 5–20
- Dunteman, George, *Principal Components Analysis, Quantitative Applications in the Social Sciences* (Thousand Oaks, CA: Sage Publications, 1989)
- Edgar, Andrew, 'Adorno and Musical Analysis', *The Journal of Aesthetics and Art Criticism*, 57 (1999), 439–49
- EGGE, Mark, 'Toward a Method for Performance Analysis of Twentieth-Century Music' (Masters dissertation, 2005)
- Eitan, Zohar, 'Intensity and Cross-Dimensional Interaction in Music: Recent Research and Its Implications for Performance Studies' (presented at the Study day, Tel Aviv: Department of Musicology, 2005), 141–66
- Eitan, Zohar, Roni Granot, 'How Music Moves: Musical Parameters and Listeners' Images of Motion', *Music Perception*, 23 (2006), 221–47
- — —, 'Intensity Changes and Perceived Similarity: Inter-Parametric Analogies', *Musicae Scientiae, Discussion Forum*, 4A, 2007, 39–75
- — —, 'Inter-Parametric Analogy and the Perception of Similarity in Music', in *Proceedings of the 5th Triennial ESCOM Conference*, ed. by Reinhard Kopiez, Andreas Lehmann, Irving Wolther, C. Wolf (presented at the ESCOM, Hannover, 2003)

- Elliott, Charles, 'Race and Gender as Factors in Judgments of Musical Performance' in *Bulletin of the Council for Research in Music Education* (presented at the 15th International Society for Music Education: ISME Research Seminar, University of Illinois Press on behalf of the Council for Research in Music Education, 1995), CXXVII, 50–56
- Elvers, Paul, Diana Omigie, Wolfgang Fuhrmann, Timo Fischinger, 'Exploring the Musical Taste of Expert Listeners: Musicology Students Reveal Tendency toward Omnivorous Taste', *Frontiers in Psychology*, 6: Article 1252
- Evens, Aden, 'Sound Ideas', in *A Shock to Thought: Expression after Deleuze and Guattari*, ed. by Brian Massumi (London: Routledge, 2002), 171–87
- Fabian, Dorottya, *A Musicology of Performance: Theory and Method based on Bach's Solos for Violin* (<http://www.openbookpublishers.com>: OpenBook Publishers, 2015), <http://dx.doi.org/10.11647/>
- — —, 'Is Diversity in Musical Performance Truly in Decline? The Evidence of Sound Recordings', *Context: A Journal of Music Research*, 31 (2006), 165–80
- Fabian, Dorottya, Eitan Ornoy, 'Identity in Violin Playing on Records: Interpretation Profiles in Recordings of Solo Bach by Early Twentieth-Century Violinists', *Performance Practice Review*, 14 (2009)
- Fabian, Dorrotya, Emery Schubert, 'Baroque Expressiveness and Stylishness in Three Recordings of the D Minor Sarabanda for Solo Violin (BWV 1004) by J. S. Bach', *Music Performance Research*, 3 (2009), 36–55
- Fabri, Franco, 'A Theory of Musical Genres: Two Applications', in *Popular Music Perspectives*, ed. by David Horn and Philip Tagg (presented at the First International Conference on Popular Music Studies, Amsterdam: Göteborg and Exeter: International Association for the Study of Popular Music, 1981), 52–81
- — —, 'Browsing Music Spaces: Categories and the Musical Mind.' (presented at the IASPM, UK, 1999)
- Feisst, Sabine, *Schoenberg's New World: The American Years* (Oxford: Oxford University Press, 2011)
- Fernandez, Alberto, Sergio Gomez, 'Solving Non-Uniqueness in Agglomerative Hierarchical Clustering Using Multidendrograms', *Journal of Classification*, 25 (2008), 43–65
- Ferretti, Roberto, Guerino Mazzola, 'Algebraic Varieties of Musical Performances', *Tatra Mountains Mathematical Publications*, 23 (2001), 59–69
- Fink, Robert, 'Rigorous (♩ = 126)": "The Rite of Spring" and the Forging of a Modernist Performing Style', *Journal of the American Musicological Society*, 52 (1999), 299–362
- Fischer, Hans, *A History of the Central Limit Theorem* (New York: Springer, 2011)
- Fisher, George, Judy Lochhead, 'Analysis, Hearing and Performance', *Indiana Theory Review*, 14 (1993), 1–36
- Fletcher, Stanley, 'For the Performer', *Journal of Music Theory*, 3 (1959), 38–49

- Flossmann, Sebastian, Gerhard Widmer, 'Towards a Multilevel Model of Expressive Piano Performance', in *Proceedings of the International Symposium on Performance Science 2011*, ed. by Aaron Williamon, Darryl Edwards, and Lee Bartel (presented at the International Symposium on Performance Science 2011, Utrecht: AEC, 2011), 641–46
- Forte, Allen, 'A Theory of Set-Complexes for Music', *Journal of Music Theory*, 8 (1964), 136–139+141+140+142–183
- — —, 'Sets and Nonsets in Schoenberg's Atonal Music', *Perspectives of New Music*, 11 (1972), 43–64
- — —, *The Structure of Atonal Music* (New Haven and London: Yale University Press, 1973)
- Friberg, Anders, 'Generative Rules for Music Performance: A Formal Description of a Rule System', *Computer Music Journal*, 15 (1991), 56–71
- Friberg, Anders, Giovanni Battel, 'Structural Communication', in *The Science and Psychology of Music Performance: Creative Strategies for Teaching and Learning*, ed. by Richard Parncutt and G McPherson (New York: Oxford University Press, 2002), 199–218
- Friberg, Anders, Erica Bisesi, 'Using Computational Models of Music Performance to Model Stylistic Variations', in *Expressiveness in Music Performance: Empirical Approaches across Styles and Cultures*, ed. by Dorottya Fabian, Renee Timmers, and Emery Schubert (Oxford: OUP, 2014), 240–59
- Friberg, Anders, Roberto Bresin, 'Director Musices: The KTH Performance Rules System', in *Proceedings of SIGMUS-46*, 2002, 43–48
- Friberg, Anders, Roberto Bresin, Johan Sundberg, 'Overview of the KTH Rule System for Musical Performance', *Advances in Cognitive Psychology*, 2 (2006), 145–61
- Friberg, Anders, Lars Fryden, Lars-Gunnar Bodin, Johan Sundberg, 'Performance Rules for Computer-Controlled Contemporary Keyboard Music', *Computer Music Journal*, 15 (1991), 49–55
- Friedmann, Michael, 'A Methodology for the Discussion of Contour: Its Application to Schoenberg's Music', *Journal of Music Theory*, 29 (1985), 223–48
- Friedrich, Otto, *Glenn Gould: A Life and Variations*, Reprint. (NY: Random House, 1990)
- Frisch, Walter, *Brahms and the Principle of Developing Variation* (Berkeley: University of California Press, 1984)
- Frish, Walter, *Schoenberg and His World* (Princeton University Press, 1999),  
[http://books.google.ie/books?id=AF-L921gjuAC&pg=PA287&lpg=PA287&dq=RILM+schoenberg&source=bl&ots=Flu6pL-q4j&sig=eZQYym3iOV-RCyMafZ\\_qIUuXO0c&hl=en&ei=0nb7TLy2ItWAhAfp4\\_CTCw&sa=X&oi=book\\_result&ct=result&resnum=8&ved=0CEQQ6AEwBw#v=onepage&q&f=false](http://books.google.ie/books?id=AF-L921gjuAC&pg=PA287&lpg=PA287&dq=RILM+schoenberg&source=bl&ots=Flu6pL-q4j&sig=eZQYym3iOV-RCyMafZ_qIUuXO0c&hl=en&ei=0nb7TLy2ItWAhAfp4_CTCw&sa=X&oi=book_result&ct=result&resnum=8&ved=0CEQQ6AEwBw#v=onepage&q&f=false), Accessed: 5 December 2010
- Frith, Simon, 'Music and Identity', in *Questions of Cultural Identity*, ed. by Stuart Hall and Paul du Gay (London: Sage Publications, 2003), 108–27

- — —, *Performing Rites: Evaluating Popular Music* (Oxford: Oxford University Press, 1996)
- Fuad, Muhammad, Pierre-Francois Marteau, 'Enhancing the Symbolic Aggregate Approximation Method Using Updated Lookup Tables', *Lecture Notes in Computer Science* (presented at the Knowledge-Based and Intelligent Information and Engineering Systems (KES'2010, Cardiff: Springer Verlag, 2010), 6276/2010, 420–31
- Gabrielsson, Alf, 'Expressive Intention and Performance', in *The Psychology of Music*, ed. by Reinhart Steinberg (San Diego: Academic Press, 1999), 501–602
- — —, 'Music Performance Research at the Millenium', *Psychology of Music*, 31 (2003), 221–72
- — —, 'Performance of Rhythm Patterns', *Scandinavian Journal of Psychology*, 15 (1974), 63–72
- Gabrielsson, Alf, Ingmar Bengtsson, Barbro Gabrielsson, 'Performance of Musical Rhythm in 3/4 and 6/8 Meter', *Scandinavian Journal of Psychology*, 24 (1983), 193–213
- Gabrielsson, Alf, Erik Lindström, 'The Role of Structure in the Musical Expression of Emotions', in *Handbook of Music and Emotion*, ed. by Patrick Juslin and John Sloboda (Oxford: OUP, 2010), 367–400
- Gelfand, Stanley, *Essentials of Audiology* (New York: Thieme, 2009)
- Geringer, John, 'Continuous Loudness Judgements of Dynamics in Recorded Music Excerpts', *Journal of Research in Music Education*, 43, 22–35
- Ginsborg, Jane, 'Strategies for Memorizing Music', in *Musical Excellence: Strategies and Techniques to Enhance Performance* (Oxford: Oxford University Press, 2004), 123–42
- Gjerdingen, Robert, 'Review of Cognitive Foundations of Musical Pitch by Carol L. Krumhansl', *Music Perception*, 9 (1992), 476–92
- Godlovitch, Stanley, *Musical Performance: A Philosophical Study* (London: Routledge, 1998)
- Goebl, Werner, 'Melody Lead in Piano Performance: Expressive Device or Artefact?', *The Journal of the Acoustical Society of America*, 110 (2001), 563–72
- — —, 'Skilled Piano Performance: Melody Lead Caused by Dynamic Differentiation', in *Proceedings of the 6th International Conference on Music Perception and Cognition* (presented at the 6th International Conference on Music Perception and Cognition, American Psychological Association, 2000)
- Goebl, Werner, Roberto Bresin, Alexander Galembo, 'Once Again: The Perception of Piano Touch and Tone. Can Touch Audibly Change Piano Sound Independently of Intensity?', in *Proceedings of the International Symposium on Musical Acoustics* (presented at the ISAM2004, Nara, Japan, 2004), 332–35
- Goebl, Werner, Simon Dixon, Giovanni De Poli, Anders Friberg, Roberto Bresin, Gerhard Widmer, 'Sound to Sense – Sense to Sound: A State of the Art in Sound and Music Computing', in *Sense in Expressive Music Performance: Data Acquisition, Computational Studies, and Models*, eds. Pietro Politti, David Rocchesso (Berlin: Logos, 2008), 195–242

- Goebel, Werner, Simon Dixon, Emery Schubert, 'Quantitative Methods: Motion Analysis, Audio Analysis, Continuous Response Techniques', in *Expressiveness in Music Performance: Empirical Approaches across Styles and Cultures* (Oxford: OUP, 2014), 221–39
- Goebel, Werner, Elias Pampalk, Gerhard Widmer, 'Exploring Expressive Performance Trajectories: Six Famous Pianists Play Six Chopin Pieces', in *Proceedings of the 8th International Conference on Music Perception and Cognition (ICMPC'04)*, (presented at the 8th International Conference on Music Perception and Cognition (ICMPC'04), Evanston, Illinois, 2004)
- Goodall, Howard, *The Story of Music* (London: Random House, 2013)
- Grachten, Maarten, Josep Arcos, Lopez De Mantaras, 'Melody Retrieval Using the Implication/Realization Models', in *Proceedings of 6th Int. Conf. on Music Information Retrieval*, 2005
- Grachten, Maarten, Josep Arcos, Ramon Lopez de Mantanaras, 'Melodic Similarity: Looking for a Good Abstraction Level', in *Proceedings of 5th International Conference on Music Information Retrieval* (presented at the ISMIR 2004, Barcelona: Audiovisual Institute, Universitat Pompeu Fabra, 2004)
- Grachten, Maarten, Gerhard Widmer, 'Linear Basis Models for Prediction and Analysis of Musical Expression', *Journal of New Music Research*, 41 (2012), 311–22
- — —, 'Who Is Who in the End? Recognizing Pianists by Their Final Ritardandi', in *Proceedings of the International Society for Music Information Retrieval 2009* (International Society for Music Information Retrieval, 2009)
- Gracyk, Theodore, 'Adorno, Jazz, and the Aesthetics of Popular Music', *The Musical Quarterly*, 76 (1992), 526–42
- — —, 'Listening to Music: Performances and Recordings', *The Journal of Aesthetics and Art Criticism*, 55 (1997), 139–50
- Granat, Zbigniew, 'Rediscovering "Sonoristics": A Groundbreaking Theory from the Margins of Musicology', in *Music's Intellectual History: Founders, Followers and Fads*, presented at First Conference of the Répertoire International de Littérature Musicale, The City University of New York Graduate Center, 16–19 March 2005 (RILM, 2005), <http://www.rilm.org/historiography/granat.pdf>, Accessed: 13 August 2017
- Hailey, Christopher, 'Schoenberg and the Canon: An Evolving Heritage', in *Constructive Dissonance: Arnold Schoenberg and the Transformations of Twentieth-Century Culture*, eds. Juliane Brand, Christopher Hailey (Berkeley: University of California Press, 1997)
- Haimo, Ethan, 'Analysis and the Intentional Fallacy', *Music Theory Spectrum*, 18 (1996), 167–99
- Hargreaves, David, Raymond McDonald, Dorothy Miel, 'How Do People Communicate Using Music?', in *Musical Communication*, eds. David Hargreaves, Raymond McDonald, Dorothy Miel (Oxford: OUP, 2005), 1–25
- Harrington, Peter, *Machine Learning in Action* (New York: Manning Publications, 2012)

- Hasty, Christopher, 'Form and Idea in Schoenberg's Phantasy', in *Music Theory in Concept and Practice*, eds. James Baker, David Beach, Jonathan Bernard (Rochester NY: University of Rochester Press, 1997), 459–79
- Heaton, Roger, 'Contemporary Performance Practice and Tradition', *Music Performance Research*, 5 (2012), 96–104
- Hermann, Thomas, Andy Hunt, John Neuhoff, eds., *The Sonification Handbook* (Berlin: Logos Verlag Berlin GmbH, 2011)
- Heroux, Isabelle, 'Creative Processes in the Shaping of a Musical Interpretation: A Study of Nine Professional Musicians', *Frontiers in Psychology*, 9:665, <https://doi.org/10.3389/psyg.2018.00665>
- Hevner, Kate, 'Experimental Studies of the Elements of Expression in Music', *American Journal of Psychology*, 48 (1936), 246–68
- Hill, Richard, 'Review of Arnold Schoenberg's Phantasy for Violin, First Edition', *Music Library Association: Notes*, 9 (1952), 647–48
- Hong, Ju-Lee, 'An Empirical Analysis of Musical Expression in Recordings by Selected Cellists' (Masters dissertation, Goldsmiths, University of London, 2014), <http://research.gold.ac.uk/10156>, Accessed: 18 August 2015
- Honing, Henkjan, 'Evidence for Tempo-Specific Timing in Music Using a Web-Based Experimental Setup', *Journal of Experimental Psychology*, 32 (2006), 780–86
- — —, 'Is Expressive Timing Relational Invariant under Tempo Transformation?', *Psychology of Music*, 35 (2007), 276–85
- — —, 'On the Growing Role of Observation, Formalization and Experimental Method in Musicology', *Empirical Musicology Review*, 1 (2006), 2–6, <http://hdl.handle.net/1811/21901>
- — —, 'The Comeback of Systematic Musicology: New Empiricism and the Cognitive Revolution', *Tijdschrift Voor Musiektheorie*, 9 (2004), 241–44
- — —, 'The Potential of the Internet for Music Perception Research: A Comment on Lab-Based Versus Web-Based Studies', *Empirical Musicology Review*, 3 (2008), 4–7
- Honing, Henkjan, Olivia Ladinig, 'The Potential of the Internet for Music Perception Research: A Comment on Lab-Based Versus Web-Based Studies', *Empirical Musicology Review*, 3 (2008), 4–7
- Honing, Henkjan, 'On Music Performance, Theories, Measurement and Diversity', in *Cognitive Processing*, ed. by M.A. Belardinelli, International Quarterly of Cognitive Sciences, 2002
- Huettenrauch, Tina, 'Three Case Studies in Twentieth-Century Performance Practice' (PhD dissertation, 2012)
- Humphrey, Eric, Juan Bello, 'Moving beyond Feature Design: Deep Architectures and Automatic Feature Learning in Music Informatics', in *Proceedings of the 13th International Society for Music*



- Information Retrieval Conference* (presented at the 13th International Society for Music Information Retrieval Conference (ISMIR 2012), FEUP Edições, 2012), 403–8
- Huovinen, Erkki, 'Varieties of Musicological Empiricism', *Empirical Musicology Review*, 1 (2006), 12–27, <http://hdl.handle.net/1811/24071>
- Huron, David, *Sweet Anticipation: Music and the Psychology of Expectation* (MA: MIT Press, 2006)
- Huron, David, Elizabeth Margulis, 'Music Expectancy and Thrills', in *Handbook of Music and Emotion: Theory, Research, Applications*, ed. by Patrick Juslin and John Sloboda (Oxford: Oxford University Press, 2010), §21.3
- Iddon, Martin, *New Music at Darmstadt: Nono, Stockhausen, Cage, and Boulez* (Cambridge: Cambridge University Press, 2013)
- Ingarden, Roman, 'Essay 1 - The Musical Work', in *The Ontology of the Work of Art*, trans. by Raymond Meyer and John Goldthwait (Ohio: Ohio University Press, 1989)
- Inselberg, Alfred, 'Multidimensional Detective', in *Proceedings of the IEEE Symposium on Information Visualization* (presented at the InfoVis '97, IEEE, 1997), 100–107
- Inverne, James, 'Masterpieces or Fakes? The Joyce Hatto Scandal', *Gramophone*, 21 February 2007, <http://www.gramophone.co.uk/editorial/masterpieces-or-fakes-the-joyce-hatto-scandal-february-15-2007>, Accessed: 21 December 2013
- Jackson, Roland, 'Schoenberg as Performer of His Own Music', *Journal of Musicological Research*, 24 (2005), 49–69
- Johnson, Peter, 'The Legacy of Recordings', in *Musical Performance: A Guide to Understanding*, ed. John Rink (Cambridge, 2002)
- Juslin, Patrick, 'Can Results from Studies of Perceived Expression in Music Performances Be Generalized across Response Formats?', *Psychomusicology*, 16 (1997), 77–101
- — —, 'Studies of Musical Performance: A Theoretical Analysis of Empirical Findings', in *Proceedings of the Stockholm Music Acoustics Conference*, ed. by Roberto Bresin (Stockholm: Department of Speech, Music, and Hearing, Royal Institute of Technology, 2003), II, 513–16
- Juslin, Patrick, Anders Friberg, Bresin, 'Towards a Computational Model of Expression in Music Performance: The GERM Model', *Musicae Scientiae*, 2002, 63–122
- Juslin, Patrick, Simon Liljeström, Daniel Västfjäll, Ana Silva, 'An Experience Sampling Study of Emotional Reactions to Music: Listener, Music, Situation', *Emotion*, 8 (2008), 668–83
- Juslin, Patrick, John Sloboda, eds., *Music and Emotion: Theory and Research*, Series in Affective Science, 1st edn, 2001
- Juslin, Patrick, Daniel Västfjäll, 'Emotional Responses to Music: The Need to Consider Underlying Mechanisms', *Behavioral and Brain Sciences*, 31 (2008), 559–621

- Kaiser, Florian, 'Music Structure Segmentation' (M.Sc. dissertation, Technischen Universität Berlin, 2012)
- Kanno, Mieko, 'Thoughts on How to Play in Tune: Pitch and Intonation', *Contemporary Music Review*, 22 (2003), 35–52
- — —, 'Thoughts on How to Play in Tune: Pitch and Intonation', *Contemporary Music Review*, 22 (2003), 35–52
- Karakelle, Sibel, 'The Carriers of the Enlightenment: Mozart and Rousseau in the 18th Century Europe', *Humanity and Social Sciences Journal*, 2 (2007), 23–28
- Katz, Mark, 'Capturing Sound: How Technology Has Changed Music', *Washington Post* (Washington, 26 July 2005), <http://www.washingtonpost.com/wp-dyn/content/discussion/2005/07/21/DI2005072101733.html>, Accessed: 26 January 2016
- — —, 'Portamento and the Phonograph Effect', *Journal of Musicological Research*, 25 (2006), 211–32
- Kaufman, Leonard, Peter Rousseeuw, 'Clustering by Means of Medoids' (ResearchGate, 1987), [www.researchgate.net/publication/243777819](http://www.researchgate.net/publication/243777819), Accessed: 13 June 2017
- Kelleher, John, Brian MacNamee, Aoife D'Arcy, *Fundamentals of Machine Learning for Predictive Data Analytics: Algorithms, Worked Examples, and Case Studies*, 1st edn (Boston: MIT Press, 2015)
- Kendall, Roger, 'Commentary on "The Potential of the Internet for Music Perception Research: A Comment on Lab-Based Versus Web-Based Studies" by Honing & Ladinig', *Empirical Musicology Review*, 2 (2008), 8–10, <http://hdl.handle.net/1811/31693>
- Kendall, Roger, Edward Carterette, 'The Communication of Musical Expression', *Music Perception*, 8 (1990), 129–64
- Keogh, Eamonn, Kaushik Chakrabarti, Michael Pazzani, Sharad Mehrotra, 'Dimensionality Reduction for Fast Similarity Search in Large Time Series Databases', *Journal of Knowledge and Information Systems*, 3 (2001), 263–86
- Keogh, Eamonn, Abdullah Mueen, 'Curse of Dimensionality', ed. by Claude Sammut and Geoffrey Webb, *Encyclopedia of Machine Learning* (New York: Springer, 2010)
- Kirke, Alexander, Eduardo Miranda, eds., *Guide to Computing for Expressive Music Performance* (London: Springer, 2013)
- Kivy, Peter, *An Introduction to a Philosophy of Music* (Oxford: OUP, 2002)
- Klein, Eve, 'Is Classical Music Boring? A Discussion of Fidelity, Virtuosity and Performance in Classical Music Recording', in *Communities, Places, Ecologies: Proceedings of the 2013 IASPM-ANZ Conference*, ed. by Jadey O'Regan and Toby Wren (presented at the 2013 IASPM-ANZ Conference, Brisbane: IASPM Australia/New Zealand, 2014), 112–25
- — —, 'Performing Nostalgia on Record: How Virtual Orchestras and YouTube Ensembles Have Problematised Classical Music', *Journal on the Art of Record Production*, 2015

- Kohonen, Teuvo, 'The Self Organising Map', *Proceedings of the IEEE*, 78 (1990), 1464–80
- Kolisch, Rudolf, 'Schoenberg as a Performing Artist', *Tempo, New Series*, 193 (1995), 34–35
- Konečni, Vladimir, 'On Philosophical and Empirical Aesthetics', in *Proceedings of Person. Color. Nature. Music 2005* (presented at the Person. Color. Nature. Music, Daugavpils, Latvia, 2005), 46–55
- Konečni, Vladimir, Mitchell Karno, 'Empirical Investigations of the Hedonic and Emotional Affects of Musical Structure', in *Jahrbuch Der Deutschen Gesellschaft Fur Musikpsychologie*, ed. by Klaus-Ernst Behne, Günter Kleinen, Helga de la Motte-Haber (Wilhelmshaven: Florian Noetzel GmbH, 1994), 11, 119–37
- Krumhansl, Carol, 'A Perceptual Analysis of Mozart's Piano Sonata K.282', *Music Perception*, 13 (1996), 401–32
- — —, 'An Exploratory Study of Musical Emotions and Psychophysiology', *Canadian Journal of Experimental Psychology*, 51 (1997), 336–53
- — —, *Cognitive Foundations of Musical Pitch*, Oxford Psychology Series 17 (New York: Oxford University Press, 1990)
- Lane, David, 'Introduction to Linear Regression', in *Online Statistics Education: A Multimedia Course of Study* ([Http://Onlinestatbook.Com/](http://Onlinestatbook.Com/)), ed. by David Lane (Rice University), <http://onlinestatbook.com/2/regression/intro.html>, Accessed: 28 June 2018
- Langner, Jörg, Werner Goebel, 'Visualizing Expressive Performance in Tempo-Loudness Space', eds. Tim Crawford, Lorna Gibson, *Computer Music Journal*, 27 (2003), 69–83
- Lapidaki, Eleni, 'Consistency of Tempo Judgements as a Measure of Time Experience in Music' (PhD dissertation, Northwestern University, 1996)
- Large, Edward, Caroline Palmer, Jordan Pollack, 'Reduced Memory Representations for Music', *Cognitive Science*, 19 (1995), 53–96
- Larson, Steve, 'A Tonal Model of an "Atonal" Piece: Schoenberg's Opus 15, Number 2', *Perspectives of New Music*, 25 (1987), 418–33
- Lee, Sang-Hyuk, Hee-Jun Kwon, Hyun-Jin Choi, Nam-Hun Lee, Sung-Jin Lee, Sung-Min Jin, 'The Singer's Formant and Speaker's Ring Resonance: A Long-Term Average Spectrum Analysis', *Clinical and Experimental Otorhinolaryngology*, 1 (2008), 92–96
- Lee, Sheri, 'Four Twelve-Tone Violin Compositions: Performance Practice and Preparation' (DMA dissertation, 2009), University of Cincinnati, College-Conservatory of Music
- Leech-Wilkinson, Daniel, 'Compositions, Scores, Performances, Meanings', *Music Theory Online* (MTO), 18 (2012), <http://mtosmt.org/issues/mto.12.18.1/mto.12.18.1.leech-wilkinson.php>, Accessed: 24 June 2016
- — —, 'Musicology and Performance', in *Music's Intellectual History: Founders, Followers, and Fads*, ed. by Zdravko Blazekovic and Barbara Mackenzie (New York: RILM, 2009), 791–803

- — —, 'Portamento and Musical Meaning', *Journal of Musicological Research*, 25 (2010), 233–61
- — —, 'Recordings and Histories of Performance Style', in *The Cambridge Companion to Recorded Music*, ed. by Nicholas Cook, Eric Clarke, Daniel Leech-Wilkinson, John Rink (Cambridge: Cambridge University Press, 2009), 246–62
- — —, *The Changing Sound of Music: Approaches to Studying Recorded Musical Performances*, 1.1 (London: CHARM, 2010), <http://www.charm.rhul.ac.uk/studies/chapters/intro.html>, Accessed: 15 June 2016
- Lehmann, Andreas, K Ericsson, 'Research on Expert Performance and Deliberate Practice Implications for the Education of Amateur Music Students', *Psychomusicology: Music, Mind and Brain*, 16 (1997), <http://ojs.vre.upei.ca/index.php/psychomusicology/article/view/465>, Accessed: 14 December 2015
- Lehrdahl, Fred, Ray Jackendorff, *A Generative Theory of Tonal Music* (MA: MIT Press, 1983)
- Leman, Marc, 'Systematic Musicology at the Crossroads of Modern Music Research', in *Systematic and Comparative Musicology: Concepts, Methods, Findings*, ed. by Albrecht Schneider, *Hamburger Jahrbuch für Musikwissenschaft* (Frankfurt: Peter Lang, 2008), 89–115
- — —, 'The Need for a Cross-Cultural Empirical Musicology', *Empirical Musicology Review*, 8 (2013), 19–22
- Leman, Marc, Antonio Camurri, 'Understanding Musical Expressiveness Using Interactive Multimedia Platforms', ed. by Richard Parncutt, *Musicae Scientiae (Special Issue on Interdisciplinary Musicology)*, 2006, 209–33
- de Leon, Pedro, Inesta, Jose, 'Pattern Recognition Approach for Music Style Identification Using Shallow Statistical Descriptors', *IEEE Transactions on Systems, Man, and Cybernetics—Part C: Applications and Reviews*, 37 (2007), 248–57
- Lester, Joel, 'Analysis and Performance in Schoenberg's Phantasy, Op. 47', in *Pianist, Scholar, Connoisseur: Essays in Honor of Jacob Lateiner*, ed. by Bruce Brubaker and Jane Gottlieb, *Festschrift Series*, 15 (Pendragon Press, 2000), 151–74
- Levenshtein, Valdimir, 'Binary Codes Capable of Correcting Deletions, Insertions, and Reversals', *Soviet Physics Doklady*, 10 (1966), 707–10
- Levitin, Daniel, 'Editorial: Introduction to the Angel of Death Project', ed. Lola Cuddy, *Music Perception*, 22 (2004), 167–70
- Levitin, Daniel, Bradley Vines, Regina Nuzzo, 'Quantifying Musical Dynamics: Analyzing Musical Emotion with Differential Calculus and Functional Data Objects', in *Proceedings of the 8th International Conference on Music Perception & Cognition*, eds. Scott Lipscomb, Richard Ashley, Robert Gjerdingen, Peter Webster (Adelaide: Causal Productions, 2004), 449–50
- Lewin, David, 'A Study of Hexachord Levels in Schoenberg's Violin Fantasy', *Perspectives of New Music*, 6 (1967), 18–32

- — —, *Generalized Musical Intervals and Transformations* (New Haven: Yale University Press, 1987)
- — —, 'Transformational Techniques in Atonal and Other Music Theories', *Perspectives of New Music*, 21 (1982), 312–71
- Liao, T. Warren, 'Clustering of Time Series Data - a Survey', *Pattern Recognition*, 38 (2005), 1857–74
- Liebman, Elad, Eitan Ornoy, Benny Chor, 'A Phylogenetic Approach to Music Performance Analysis', *Journal of New Music Research*, 41 (2012), 215–42
- Lin, Jessica, Eamonn Keogh, Stefano Lonardi, Bill Chiu, 'A Symbolic Representation of Time Series, with Implications for Streaming Algorithms' (presented at the *8th ACM SIGMOD Workshop on Research Issues in Data Mining and Knowledge Discovery*, San Diego: ACM, 2003)
- Lin, Jessica, Eamonn Keogh, Li Wei, Stefano Lonardi, 'Experiencing SAX: A Novel Symbolic Representation of Time Series', *Data Mining Knowledge Discovery*, 15 (2007), 107–44
- Lin, Jessica, Yuan Li, 'Finding Structural Similarity in Time Series Data Using Bag-Of-Patterns Representation', in *Proceedings of 21st International Conference on Scientific and Statistical Database Management*, ed. Marianne Winslett (presented at the SSDBM 2009, Berlin: Springer, 2009), 461–77
- Lindauer, Martin, *The Expressiveness of Perceptual Experience: Physiognomy Reconsidered* (Amsterdam: John Benjamins Publishing, 2013)
- Livingstone, S, R Muhlberger, A Brown, 'Playing with Affect: Music Performance with Awareness of Score and Audience.', presented at the Australasian Computer Music Conference, Eds. T. Opie and A. R. Brown. (Brisbane: ACMA, 2005), 92–98
- Loehr, Janeen, Edward Large, Caroline Palmer, 'Temporal Coordination and Adaptation to Rate Change in Music Performance', *Journal of Experimental Psychology*, 37 (2011), 1292–1309
- Lofft, Alan, 'The Decibel (DB) and the Violin/Piano Recital', *Audioholics: Online A/V Magazine*, 1 October 2008, <https://www.audioholics.com/editorials/the-decibel-db>, Accessed 14 May 2018
- London, Justin, 'Temporal Complexity in Modern and Post-Modern Music: A Critique from Cognitive Aesthetics', in *Unfolding Time: Studies in Temporality in Twentieth Century Music*, ed. Darla Crispin, Collected Writings of the Orpheus Institute (Leuven: Leuven University Press, 2009), 9, 45–68
- Lorenzi, Michael, 'Similarity Measures in the World of Music' (Masters dissertation, Swiss Federal University of Technology, 2007)
- MacDonald, Malcolm, *Schoenberg*, 2nd edn (Oxford: OUP, 2008)
- MacRitchie, Jennifer, 'Elucidating Musical Structure through Empirical Measurement of Performance Parameters' (PhD dissertation, University of Glasgow, 2011), <http://theses.gla.ac.uk/2357/>, Accessed: 15 August 2018

- MacRitchie, Jennifer, Bryony Buck, Nicholas Bailey, ‘Gestural Communications: Linking Multimodal Analysis of Performance to Perception of Musical Structure’ (presented at the International Symposium on Performance Science, Utrecht: AEC, 2009)
- MacRitchie, Jennifer, Hubert Eiholzer, ‘Exploring the Perceptual Effects of Performers’ Interpretations’, *Journal of Interdisciplinary Music Studies*, 6 (2012), 177–200
- Maechler, Martin, Peter Rousseeuw, Anja Struyf, Mia Hubert, Hornik, Kurt, Matthias Studer, ‘PAM’, in *Finding Groups in Data: Cluster Analysis Extended* (CRAN, 2017), 45–48, <https://cran.r-project.org/web/packages/cluster/cluster.pdf>, Accessed 20 January 2017
- Marchini, Marco, ‘Analysis of Ensemble Expressive Performance in String Quartets: A Statistical and Machine Learning Approach’ (PhD dissertation, Universitat Pompeu Fabra, 2014)
- Margulis, Elizabeth, ‘A Model of Melodic Expectation’, *Music Perception*, 22 (2005), 663–714
- Marsden, Alan, ‘Interrogating Melodic Similarity: A Definitive Phenomenon or the Product of Interpretation’, *Journal of New Music Research*, 41 (2012), 323–35
- — —, ‘Position Paper: Counselling a Better Relationship between Mathematics and Musicology’, *Journal of Mathematics and Music*, 6 (2012), 145–53
- — —, ‘Response to Guerino Mazzola’, *Journal of Mathematics and Music*, 6 (2012), 103–6
- — —, “‘What Was the Question?’: Music Analysis and the Computer”, in *Modern Methods for Musicology* (England: Ashgate, 2009), 137–47
- Martingo, Angelo, ‘Communicating Music: Structure, Cognition, Expression’, in *Proceedings of the International Symposium on Performance Science 2013* (presented at the International Symposium on Performance S, Brussels: Association Europeene des Conservatoires, 2013), 823–28
- Mas, Jose, ‘Measuring Similarity of Automatically Extracted Melodic Pitch Contours for Audio-Based Query by Humming of Polyphonic Music Collections’ (Masters in Sound and Music Computing, Universitat Pompeu Fabra, 2013)
- Massumi, Brian, ed., *A Shock to Thought: Expression after Deleuze and Guattari* (New York: Routledge, 2002)
- Matheson, Johann, *Neu-Eröffnete Orchester (1713)*, trans. by BC Cannon (Yale: Yale University Press, 1947)
- Matravers, Derek, *Art and Emotion* (Oxford: Clarendon Press, 1998)
- Mattes, Arnulf, ‘Keine Rührung-Erkenntnis: The Aesthetics of Espressivo in the “Performance Theories” of Arnold Schoenberg and Rudolf Kolisch’, *Svensk Tidskrift För Musikforskning*, 95 (2013), 109–20
- — —, ‘Performance as Critique’, in *Transformations of Musical Modernism*, ed. by Erling Gulbrandsen and Julian Johnson (Cambridge: Cambridge University Press, 2015), 245–63

- — —, 'Radiant Moments of Remembrance: On Sound Sheets in Schoenberg's Late Chamber Works', *Twentieth-Century Music*, 6 (2011), 43–62
- Mauch, Matthias, Robert MacCallum, Mark Levy, Armand Leroi, 'The Evolution of Popular Music: USA 1960-2010', *Royal Society Open Science*, 2015,  
<https://doi.org/http://dx.doi.org/10.1098/rsos.150081>
- Mazzola, Guerino, 'Mathematical Music Theory: Status Quo 2010', in *Memoirs of the Fourth International Seminar on Mathematical Music Theory* (presented at the Fourth International Seminar on Mathematical Music Theory, Mexico: Sociedad Matematica Mexicana, 2011), 4, 11–42
- — —, *Musical Performance: A Comprehensive Approach: Theory, Analytical Tools, Case Studies* (Heidelberg: Springer, 2011)
- Mazzola, Guerino, Stefan Göller, 'Performance and Interpretation', *Journal of New Music Research*, 31 (2010), 221–32
- Mazzola, Guerino, Oliver Zahorka, 'Hierarchies of Performance Fields', *Computer Music Journal*, 18 (1994), 40–52
- McAdams, Stephen, Bradley Vines, Sandrine Viellard, Bennett Smith, Roger Reynolds, 'Influences of Large-Scale Form on Continuous Ratings in Response to a Contemporary Piece in a Live Concert Setting', *Music Perception*, 22 (2004), 297–350
- McFee, Brian, Daniel Ellis, 'Analyzing Song Structure with Spectral Clustering', eds. Hsin-Min Wang, Yi-Hsuan Yang, Jin Lee (presented at the *5th International Society for Music Information Retrieval Conference, ISMIR*, 2014), 405–10
- McGilvray, Douglas, 'On the Analysis of Musical Performance by Computer' (PhD dissertation, University of Glasgow, 2008)
- McIntyre, Philip, 'The Systems Model of Creativity: Analyzing The Distribution of Power in The Studio', *Journal on the Art of Record Production*, 03 (2008)
- Meier, Leslie, 'Promotional Ubiquitous Musics: Recording Artists, Brands, and "Rendering Authenticity"', *Popular Music and Society*, 34 (2011), 399–415
- Meyer, Leonard, *Emotion and Meaning in Music* (Chicago: University of Chicago Press, 1956)
- — —, *Style and Music: Theory, History, and Ideology* (Chicago: University of Chicago Press, 1989)
- Milton Babbitt, 'Past and Present Concepts of the Nature and Limits of Music', in *Perspectives on Contemporary Music Theory*, eds. Benjamin Boretz, Edward Cone (NY: Norton, 1972), 10–21
- Mine Dogantan-Dack, 'Artistic Research in Classical Music Performance', *PARSE-Platform for Artistic Research Sweden*, 1 (2015), 27–40
- Moelants, Dirk, 'Preferred Tempo Reconsidered', in *Proceedings of the 7th International Conference on Music Perception and Cognition*, eds. Catherine Stevens, Denis Burnham, Gary McPherson,

- Emery Schubert, James Renwick (presented at the 7th International Conference on Music Perception and Cognition, Adelaide: Causal Productions, 2002)
- — —, ‘Statistical Analysis of Written and Performed Music. A Study of Compositional Principles and Problems of Coordination and Expression in “Punctual” Serial Music’, *Journal of New Music Research*, 29 (2000), 37–60
- Molina-Solana, Miguel, Josep Arcos, Emilia Gomez, ‘Using Expressive Trends for Identifying Violin Performers’, in *Proceedings of the 9th International Conference on Music Information Retrieval* (presented at the ISMIR 2008, Lulu.com: Youngmoo Kim, 2008), 495–500,  
<http://www.lulu.com/shop/douglas-turnbull-and-juan-pablo-bello-and-elaine-chew/proceedings-of-the-9th-international-conference-on-music-information-retrieval-conference-edition/ebook/product-17432393.html>, Accessed: 14 July 2017
- Molina-Solana, Miguel, Maarten Grachten, ‘Nature versus Culture in Ritardando Performances’, in *Proceedings of the Sixth Conference on Interdisciplinary Musicology*, 2010, 23–24
- Montalto, Placido, Marco Aliotta, Andrea Cannata, Carmelo Cassisi, Alfredo Pulvirenti, ‘Similarity Measures and Dimensionality Reduction Techniques for Time Series Data Mining’, in *Advances in Data Mining Knowledge Discovery and Applications*, ed. by Adem Karahoca, 2012,  
<http://dx.doi.org/10.5772/49941>
- Montero, Pablo, Jose Vilar, ‘TSclust: An R Package for Time Series Clustering’, *Journal of Statistical Software*, 62 (2014), 1–43
- Moylan, William, *Understanding and Crafting the Mix: The Art of Recording* (Oxford: Focal Press, 2007)
- Müller, Meinard, Peter Grosche, Frans Wiering, ‘Automated Analysis of Performance Variations in Folk Song Recordings’ (presented at the MIR’10, ACM, 2010)
- Muxeneder, Therese, ‘Research Note’ (Arnold Schönberg Center, 2018),  
<https://www.schoenberg.at/index.php/de/joomla-license-sp-1943310035/phantasy-for-violin-with-piano-accompaniment-op-47-1949>, Accessed 21 December 2018
- Narmour, Eugene, *Explorations in Music, the Arts and Ideas: Essays in Honor of Leonard B. Meyer* (New York: Pendragon Press, 1988)
- — —, ‘On the Relationship of Analytical Theory to Performance and Interpretation’, in *Explorations in Music, the Arts, and Ideas: Essays in Honor of Leonard B. Meyer* (NY: Pendragon Press, 1988), 317–41
- Nettl, Bruno, *The Study of Ethnomusicology: Twenty-Nine Issues and Concepts* (Urbana: University of Illinois Press, 1983)
- Newlin, Dika, ‘Schoenberg’s New Fantasy’, *The Canon: Australian Journal of Music*, 3 (1949), 83–84
- Nielsen, Klaus, ‘Apprenticeship at the Academy of Music’, eds. Tom Barone, Liora Bresler, *International Journal of Education and the Arts*, 7 (2006), 1–16



- Norrington, Roger, 'The Sound Orchestras Make', *Early Music*, 32 (2004), 2–5
- O Doherty, Eamon, 'Music for Church and Court: Influences on Marco Da Gagliano at Florence and Mantua' (MA Dissertation, Open University, 2008)
- — —, 'Measuring Performances: Empirical Musicology in a Pantonal World', Society for Musicology in Ireland, 5<sup>th</sup> Annual Postgraduate Conference, (DIT Dublin, 2012)
- — —, 'Symbolic Approximation: An Approach to Comparing Aspects of Musical Performance' (presented at the Society for Musicology in Ireland: 7th Annual Postgraduate Students' Conference, Cork Institute/ Cork School of Music, 2014)
- — —, 'Music Performance Science: Analytics and Music Recordings', in *Proceedings of the 2016 Music Technology Workshop: Establishing a Partnership Between Music Technology, Business Analytics, and Industry in Ireland* (presented at the MustWorks16, UCD, Dublin, 2016), 56–62, [http://www.ucd.ie/t4cms/MusTWork\\_2016\\_Proceedings.pdf](http://www.ucd.ie/t4cms/MusTWork_2016_Proceedings.pdf), Accessed: 15 March 2017
- — —, 'Saxify: Detecting Fraudulent Music Recordings' (presented at the SMI/ICTM-IE Annual Postgraduate Conference, Maynooth University: ICTM Ireland/SMI, 2018)
- Ojanen, Mikko, 'Mastering Kurenniemi's Rules (2012): The Role of The Audio Engineer in The Mastering Process', *Journal on the Art of Record Production*, 10 (2015)
- Ornoy, Eitan, 'Recording Analysis of J.S. Bach's G Minor Adagio for Solo Violin (Excerpt): A Case Study', *Journal of Music and Meaning*, 6 (2008)
- Ozaslan, Tan, Josep Arcos, 'Legato and Glissando Identification in Classical Guitar', in *Proceedings of the 7th Sound and Music Computing Conference* (presented at the 7th Sound and Music Computing Conference, Barcelona, 2010), SEC. 67, 1–7
- Packalen, Elina, 'Musical Feelings and Atonal Music', *Postgraduate Journal of Aesthetics*, 2 (2005), 97–104
- Paddison, Max, *Adorno's Aesthetics of Music* (Cambridge: Cambridge University Press, 1993)
- Palmer, Caroline, 'Music Performance', *Annual Review of Psychology*, 48 (1997), 115–38
- Palmer, Caroline, Carol Krumhansl, 'Pitch and Temporal Contributions to Musical Phrase Perception: Effects of Harmony, Performance Timing, and Familiarity', *Perception and Psychophysics*, 41 (1987), 505–18
- Pampalk, Elias, 'Computational Models of Music Similarity and Their Application in Music Information Retrieval' (Doctor of Technical Sciences, 2006)
- Parncutt, Richard, 'Applying Music Psychology to Music Education: Can Perceptual Theory Inform Undergraduate Harmony?' (presented at the International Music Education Research Symposium, Launceston, Tasmania, 1999), 254–58
- — —, 'Can Researchers Help Artists? Music Performance Research for Music Students', *Music Performance Research*, 1 (2007), 1–15

- — —, ‘Systematic Musicology and the History and Future of Western Musical Scholarship’, *Journal of Interdisciplinary Music Studies*, 1 (2007), 1–32
- Pearce, Marcus, Geraint Wiggins, ‘Auditory Expectation: The Information Dynamics of Music Perception and Cognition’, *Topics in Cognitive Science*, 4 (2012), 625–52
- Pearl, Jonathan, ‘Hypothetical Universe: A Functionalist Critique of Lerdahl-Jackendoff’, *UCSB Dept of Music and Center for the Interdisciplinary Study of Music, SMPC 2003, UNLV*, 2003
- Perez, Alfonso, Esteban Maestre, Rafael Ramirez, Stefan Kersten, ‘Expressive Irish Fiddle Performance Model Informed with Bowing’, in *Proceedings of ICMC* (presented at the International Computer Music Conference, ICMA/Michigan Publishing, 2008),  
<http://hdl.handle.net/2027/spo.bbp2372.2008.115>
- Perry, Jeffrey, ‘Review of Allen Forte, *The Atonal Music of Anton Webern*’, *MTO*, 2000, [6.10]
- Pfordresher, Peter, ‘Coordination of Perception and Action in Music Performance’, *Advances in Cognitive Psychology*, 2 (2006), 183–98
- Philip, Robert, *Early Recordings and Musical Style: Changing Tastes in Instrumental Performance 1900-1950* (Cambridge: Cambridge University Press, 1992)
- — —, *Performing Music in the Age of Recording* (Cambridge: Cambridge University Press, 2004)
- Pieterse, Vreda, Paul Black, eds., *Dictionary of Algorithms and Data Structures* (US National Institute of Standards and Technology, 2008), <https://xlinux.nist.gov/dads/HTML/Levenshtein.html>,  
 Accessed: 28 December 2014
- Platz, Friedrich, Reinhard Kopiez, ‘When the Eye Listens: A Meta-Analysis of How Audio-Visual Presentation Enhances the Appreciation of Music Performance’, *Music Perception: An Interdisciplinary Journal*, 30 (2012), 71–83
- Polansky, Larry, ‘History and the Word: Form and Tonality in Schoenberg’s *Phantasy for Violin with Piano Accompaniment*’, *Ex Tempore*, 3 (1985), 29–40
- de Poli, Giovanni, Antonio Rodà, Alvis Vidolin, ‘Note-By-note Analysis of the Influence of Expressive Intentions and Musical Structure in Violin Performance’, *Journal of New Music Research*, 27 (1998), 293–321
- Popper, Karl, *The Logic of Scientific Discovery*, Translated from the Original German *Logik der Forschung* (1935), Vienna: Verlag von Julius Springer, trans. by Julius Freed and Freed Lan (London: Routledge Classics, 2002)
- Potter, John, ‘Beggar at the Door: The Rise and Fall of Portamento in Singing’, *Music and Letters*, 87 (2006), 523–50
- Povel, Dirk-Jan, ‘Temporal Structure of Performed Music: Some Preliminary Observations.’, *Acta Psychologica*, 41 (1977), 309–20
- Power Curve: Feature Extraction Plugin* (The Mazurka Project, 2006),  
<http://sv.mazurka.org.uk/MzPowerCurve/>, Accessed: 20 July 2015

- Preda-Ulita, Anca, 'Analysis and Performance: Views on the Performers' Musical Awareness', *Bulletin of the Transilvania University of Brasov, Performing Arts*, 8 (2015), 79–86
- Prior, Helen, 'Links between Music and Shape- Style-Specific; Language-Specific; or Universal?', *Topics in Musical Universals-1st International Colloquium. Conference Proceedings*, 2011
- Pullinger, Stuart, 'A System for the Analysis of Musical Data' (PhD dissertation, University of Glasgow, 2010)
- Raab, Claus, "'Fantasia Quasi Una Sonata". Zu Schonbergs "Phantasy" for Violin with Piano Accompaniment Op.47', *Melos/Neue Zeitschrift Fur Musik*, 2 (1976), 191–96
- Raffman, Diana, 'Is Twelve-Tone Music Artistically Defective?', *Midwest Studies in Philosophy*, 27 (2003), 69–87
- Raphael, Christopher, 'Symbolic and Structural Representation of Melodic Expression' (presented at the ISMIR 2009, Kobe, Japan, 2009), 555–60
- Ren, Lu, Scott Lindroth, Lawrence Carin, 'Dynamic Nonparametric Bayesian Models for Analysis of Music', *Journal of the American Statistical Association*, 105 (2010), 458–72
- Repp, Bruno, 'A Constraint on the Expressive Timing of a Melodic Gesture: Evidence from Performance and Aesthetic Judgment', *Music Perception*, 10 (1992), 221–42
- — —, 'A Microcosm of Musical Expression: II. Quantitative Analysis of Pianists' Dynamics in the Initial Measures of Chopin's Etude in E Major', *Journal of the Acoustical Society of America*, 105 (1999), 1972–88
- — —, 'Composers' Pulses: Science or Art', *Music Perception: An Interdisciplinary Journal*, 7 (1990), 423–34
- — —, 'Diversity and Commonality in Music Performance: An Analysis of Timing Microstructure in Schumann's Träumerei', *Haskins Laboratory Status Report on Speech Research*, SR-111/112, 1992, 227–60
- — —, 'Objective Performance Analysis as a Tool for the Musical Detective.', *Journal of the Acoustical Society of America*, 93 (1993), 1203–4
- — —, 'On Determining the Global Tempo of a Temporally Modulated Music Performance', *Psychology of Music*, 22 (1993), 148–56
- — —, 'Patterns of Expressive Timing in Performances of a Beethoven Minuet by Nineteen Famous Pianists', *Journal of the Acoustical Society of America*, 88 (1990), 622–41
- — —, 'Probing the Cognitive Representation of Musical Time: Structural Constraints on the Perception of Timing Perturbations', *Cognition*, 44 (1991), 241–81
- — —, 'Probing the Cognitive Representation of Musical Time: Structural Constraints on the Perception of Timing Perturbations', *Cognition*, 44 (1992), 241–81

- — —, 'Quantitative Effects of Global Tempo on Expressive Timing in Music Performance: Some Perceptual Evidence', *Music Perception*, 13 (1995), 39–57
- — —, 'The Aesthetic Quality of a Quantitatively Average Music Performance: Two Preliminary Experiments', *Music Perception*, 14 (1997), 419–44
- Reynolds, Roger, *Angel of Death* (New York: C.F. Peters, 1998)
- Ricoeur, Paul, *The Rule of Metaphor: The Creation of Meaning in Language (La Métaphore Vive)*, trans. by Robert Czerny, Kathleen McLaughlin, John Costello, English Edition (London: Routledge Classics, 2003)
- Rink, John, 'The Interpretative Shaping of Music Performance Research', *Empirical Musicology Review*, 8 (2013), 120–23
- — —, 'The State of Play in Performance Studies', in *The Music Practitioner: Research for the Music Performer, Teacher and Listener*, ed. by Jane Davidson (Aldershot: Ashgate Publishing, 2004)
- Rodriguez-Lopez, Marcelo, Anja Volk, Dimitrios Bountouridis, 'Multi-Strategy Segmentation of Melodies', ed. by Hsin-Min Wang, Yi-Hsuan Yang, Jin Lee (presented at the 5th International Society for Music Information Retrieval Conference, ISMIR, 2014), 208–12
- Ross, Alex, 'Why Do We Hate Modern Classical Music?', *The Guardian* (Manchester, 28 November 2010)
- Rowland, David, 'Chopin's Tempo Rubato in Context', in *Chopin Studies 2*, eds. John Rink, Jim Sampson (NY: Cambridge University Press, 1994), 199–213
- Rufer, Josef, *Composition with Twelve Tones*, trans. by Humphrey Searle (London: Rockliff Publishing Corporation, 1954)
- — —, *The Works of Arnold Schoenberg* (Glencoe, IL: Free Press, 1963)
- Rumson, Gordon, 'Conlon Nancarrow', in *Music of the Twentieth-Century Avant-Garde: A Biocritical Sourcebook* (Westport, CT.: Greenwood Press, 2002), 319–28
- Sabbe, Herman, 'Goeyvaerts and the Beginnings of "Punctual" Serialism and Electronic Music.', *Revue Belge de Musicologie*, 48 (1994), 55–94
- Sanchez, Monica, 'The Expressive Intonation in Violin Performance', in *Proceedings of the 9th International Conference on Music Perception and Cognition* (presented at the ICMPC9, SMPIC and ESCOM, 2006), 490–95
- Sánchez, Mónica, 'The Expressive Intonation in Violin Performance', in *Proceedings of 9th International Conference on Music Perception and Cognition* (presented at the 9th International Conference on Music Perception and Cognition, Alma Mater Studiorum University of Bologna, 2006), 490–96
- Sanden, Paul, 'Glenn Gould and Recording Technology: Linking Popular and Classical Recording Practices', in *12th Biennial IASPM International Conference Montreal 2003 Proceedings*, eds. Alex Gyde, Geoff Stahl (presented at the IASMP03, IASPM, 2003), 807–15

- Sapp, Craig, 'Computational Methods for the Analysis of Musical Structure' (PhD dissertation, 2011), Stanford University
- — —, *Dyn-a-Matic*, 2009, <http://www.mazurka.org.uk/software/online/dynamic/>, Accessed 14 January 2014
- — —, 'Hybrid Numeric/Rank Similarity Metrics for Musical Performance Analysis' (presented at the ISMIR 2008, Philadelphia, 2008), 501–6
- — —, *PowerCurve Plugin for SonicVisualiser (Header Source Code)* (The Mazurka Project, 2006), <http://www.mazurka.org.uk/software/sv/plugin/MzPowerCurve/src/MzPowerCurve.h.html>, Accessed: 14 January 2014
- — —, *Tapsnap* (The Mazurka Project), <http://mazurka.org.uk/cgi-bin/tapsnap>, Accessed: 14 March 2016
- Saraçlı, Sinan, Nurhan Doğan, İsmet Doğan, 'Comparison of Hierarchical Cluster Analysis Methods by Cophenetic Correlation', *Journal of Inequalities and Applications (Springer Open Journal)*, 2013, 1–8, <https://doi.org/10.1186/1029-242X-2013-203>
- Scheirer, Eric, 'Extracting Expressive Performance Information from Recorded Music' (MIT, 1995)
- — —, 'Using Musical Knowledge to Extract Expressive Performance Information from Audio Recordings', in *Computational Auditory Scene Analysis*, ed. by David Rosenthal and Hiroshi Okuno (New Jersey: L. Erlbaum Associates, 1998)
- Schiano, Michael, 'Grundgestalt', *Grove Music Online*, 2018, <http://www.oxfordmusiconline.com/grovemusic/abstract/10.1093/gmo/9781561592630.001.0001/omo-9781561592630-e-0000011868?rskey=2686xs&result=1>, Accessed: 28 June 2016
- Schilling, Gustav, *Encyclopädie Der Gesamten Musikalischen Wissenschaften: Oder Universal-Lexicon Der Tonkunst* (Stuttgart: Verlag den Franz Heinrich Kohler, 1840), <https://archive.org/stream/encyclopdieler06byuschi#page/4/mode/1up>, Accessed 13 January 2017
- Schmalfeldt, Janet, 'On the Relation of Analysis to Performance: Beethoven's "Bagatelles" Op. 126, Nos. 2 and 5', *Journal of Music Theory*, 29 (1985), 1–31
- Schmuckler, Mark, 'Testing Models of Melodic Contour Similarity', *Music Perception*, 16 (1999), 295–326
- Schoen, Max, 'An Experimental Study of the Pitch Factor in Artistic Singing', *Psychological Monographs*, 31 (1922), 230–59
- Schoenberg, Arnold, *Fundamentals of Musical Composition*, ed. by Gerald Strang and Leon Stein (London: Faber & Faber, 1967)
- — —, 'Letter from Schoenberg to Thor Johnson, 24 July 1950', in *Arnold Schoenberg: Letters*, ed. by Erwin Stein (Berkeley: University of California Press, 1958), 281–83
- — —, *Phantasy for Violin with Piano Accompaniment*, (New York: Peters, 1952)

- — —, *Phantasy for Violin with Piano Accompaniment*, 2<sup>nd</sup> edn., (New York: Peters, 1973)
- — —, *Schoenberg's Program Notes and Musical Analyses*, ed. by J. Daniel Jenkins, Schoenberg in Words (Oxford: OUP, 2016), v
- — —, *Style and Idea: Selected Writings of Arnold Schoenberg*, ed. by Leonard Stein, trans. by Leo Black (London: Faber and Faber, 1975)
- — —, *The musical idea and the Logic, Technique, and Art of Its Presentation* (Bloomington: Indiana University Press, 2006)
- — —, *Theory of Harmony*, trans. by Roy Carter (Berkeley: University of California Press, 1978)
- Schubert, Emery, 'Measurement and Time Series Analysis of Emotion in Music' (PhD dissertation, 1999)
- Schubert, Emery, Dorottya Fabian, 'A Taxonomy of Listeners' Judgments of Expressiveness in Music Performance', in *Expressiveness in Music Performance: Empirical Approaches across Styles and Cultures*, ed. by Dorottya Fabian (Oxford: OUP, 2014), 283–303
- Schuller, Gunther, Eduard Steuermann, 'A Conversation with Steuermann', *Perspectives of New Music*, 3 (1964), 22–35
- Scruton, Roger, *The Aesthetics of Music* (Oxford: OUP, 1997)
- — —, 'Youth Culture's Lament: Pop Culture's Noise and Glamour Try in Vain to Fill a Gaping Void', *City Journal (Manhattan Institute)* (New York, Autumn 1998), Issue 42, <https://www.city-journal.org/html/youth-culture%E2%80%99s-lament-11849.html>, Accessed: 20 September 2010
- Seashore, Carl, 'An Objective Analysis of Artistic Singing', in *Objective Analysis of Musical Performance*, ed. by Carl Seashore (Iowa City: University of Iowa Press, 1936), 12–157
- Seeger, Charles, 'An Instantaneous Music Notator', *Journal of the International Folk Music Council*, 3 (1951), 103–6
- Senin, Pavel, *Jmotif: Time Series Data Mining Toolkit Based on SAX and TFIDF Statistics*, <https://code.google.com/p/jmotif/downloads/list>, Accessed 13 April 2013
- Senin, Pavel, Sergey Malinchik, 'SAX-VSM: Interpretable Time Series Classification Using SAX and Vector Space Model' (presented at the IEEE 13th International Conference on Data Mining, New York: IEEE, 2013), 1175–80, <https://doi.org/10.1109/ICDM.2013.52>
- Serra, Joan, Meinhard Muller, Peter Grosche, Josep Arcos, 'Unsupervised Detection of Music Boundaries by Time Series Structure Features', in *Proceedings of the Twenty-Sixth AAAI Conference on Artificial Intelligence* (presented at the Twenty-sixth AAAI Conference on Artificial Intelligence, Palo Alto, California: The AAAI Press, 2012), 1613–19
- Serra, Jose, Tan Ozaslan, Josep Arcos, 'Note Onset Deviations as Musical Piece Signatures', *Plos ONE*, 8 (2013), <https://doi.org/10.1371/journal.pone.0069268>

- Shaffer, Henry, Neil Todd, 'The Interpretative Component in Musical Performance', in *Action and Perception in Rhythm and Music*, ed. by Alf Gabrielsson (Stockholm: Royal Swedish Academy of Music, 1987), 139–52
- Shaffer, L. Neil Todd, 'The Interpretative Component in Musical Performance', in *Musical Perceptions*, ed. by Rita Aiello (Oxford: OUP, 1994)
- Shaffer, L. Henry, 'Cognition and Affect in Musical Performance', *Contemporary Music Review*, 4 (1989), 381–89
- — —, 'Performance of Chopin, Bach and Bartok: Studies in Motor Programming', *Cognitive Psychology*, 13 (1981), 326–76
- — —, 'Timing in Solo and Duet Piano Performances.', *Quarterly Journal of Experimental Psychology*, 36 (1984), 577–95
- Shaffer, L. Henry, Eric Clarke, Neil Todd, 'Metre and Rhythm in Piano Playing', *Cognition*, 20 (1985), 61–77
- Shannon, Claude, 'A Mathematical Theory of Communication', *Bell Systems Technical Journal*, 27 (1948), 379–423, 623–56
- Shao, Jie, Heng Huang, Jialie Shen, Xiaofang Zhou, 'Distribution-Based Similarity Measures for Multi-Dimensional Point Set Retrieval Applications' (presented at the MM'08, Vancouver, 2008)
- Sheri Renee Lee, 'Four Twelve-Tone Violin Compositions: Performance Practice and Preparation' (Cincinnati, 2009)
- Shoaf, Wayne, *The Schoenberg Discography*, 2nd edn (Berkeley: Fallen Leaf Press, 1994)
- Singhal, Ashish, Dale Seborg, 'Clustering Multivariate Time-Series Data', *Journal of Chemometrics*, 19 (2005), 427–38
- Sirman, Berk, 'Developing Variations' (Uppsala University, 2006)
- Sitsky, Larry, *Music of the Twentieth-Century Avant-Garde: A Biocritical Sourcebook* (Westwood, CT.: Greenwood Press, 2002)
- Slaney, Malcolm, Kilian Weinberger, William White, 'Learning a Metric for Music Similarity', 2008, 313–18
- Sloboda, John, 'Music Structure and Emotional Response: Some Empirical Findings', *Psychology of Music*, 19 (1991), 110–20
- — —, *The Musical Mind: The Cognitive Psychology of Music* (Oxford: Clarendon Press, 1985)
- Small, Christopher, *Music, Society, Education* (Hanover & London: Wesleyan University Press, 1996)
- Smola, Alex, S Vishwanathan, *Introduction to Machine Learning* (Cambridge: Cambridge University Press, 2008)
- Spiro, Neta, Nicholas Cook, 'Analysing Motif in Performance', *CHARM Newsletter* (AHRC, 2009), 1–26

- Spiro, Neta, Nicholas Gold, John Rink, 'In Search of Motives: Identification of Repeated Patterns in Performances and Their Structural Contexts', in *Proceedings of ICoMCS December 2007* (presented at the Inaugural International Conference on Music Communication Science, Sydney, Australia: ed. Emery Schubert (Sydney: ARC Research Network in Human Communication Science (HCSNet), 2007), 152-4, 2007)
- Stamatatos, Efsthatis, 'A Computational Model for Discriminating Music Performers', in *Proceedings of the MOSART Workshop on Current Research Directions in Computer Music* (presented at the MOSART Workshop on Current Research Directions in Computer Music, Padova: University of Padova, 2001)
- — —, 'Quantifying the Differences between Music Performers: Score vs. Norm', in *Proceedings of the International Computer Music Conference (ICMC'2002)* (Göteborg: ICMC, 2002), 376–82
- Stamatatos, Efsthatis, Gerhard Widmer, 'Automatic Identification of Music Performers with Learning Ensembles', *Artificial Intelligence*, 165 (2005), 37–56
- — —, 'Music Performer Recognition Using an Ensemble of Simple Classifiers', in *Proceedings of the 15th European Conference on Artificial Intelligence*, ed. by Frank Harmelen (presented at the ECAI 2002, Amsterdam: IOS Press, 2002)
- Stangroom, Jeremy, *P Value from Pearson (R) Calculator* (Social Science Statistics, 2019),  
<https://www.socscistatistics.com/pvalues/pearsondistribution.aspx>, Accessed 18 December 2019
- Straus, Joseph, 'A Primer for Atonal Set Theory', *College Music Symposium*, 31 (1991), 1–26
- Stravinsky, Igor, *Le Sacre Du Printemps*, Philharmonia Orchestra, Conducted Robert Craft (Naxos, 1967)
- Sullivan, Yvette, Robert Cantwell, 'The Planning Behaviours of Musicians Engaging Traditional and Non-Traditional Scores', *Psychology of Music*, 27 (1999), 245–66
- Sundberg, Johan, 'Arriving in Time: A Major Concern for Conductors and Musicians', in *Reflections on Sound*, ed. by Peter Svensson (Trondheim: Norwegian University of Science and Technology, 2008), 17–27
- Sundberg, Johan, Violet Verillo, 'On the Anatomy of the Retard: A Study of Timing in Music', *Journal of the Acoustical Society of America*, 68 (1980), 772–79
- Sung, Alistair, Dorottya Fabian, 'Variety in Performance: A Comparative Analysis of Recorded Performances of Bach's Sixth Suite for Solo Cello from 1961 to 1998', *Empirical Musicology Review*, 6 (2011), 20–42
- Swed, Mark, 'Leonard Stein, 87; Schoenberg Institute Chief, Pianist, Teacher', *Los Angeles Times* (L.A., 25 June 2004), <http://articles.latimes.com/2004/jun/25/local/me-stein25>, Accessed: 30 June 2017
- Symes, Colin, *Setting the Record Straight: A Material History of Classical Recording* (Connecticut: Wesleyan University Press, 2004)
- Tapinos, Avraam, Pedro Mendes, 'A Method for Comparing Multivariate Time Series with Different Dimensions', *PLoS ONE*, 8 (2013), <https://doi.org/doi: 10.1371/journal.pone.0054201>



- Tarasti, Eero, *Myth and Music: A Semiotic Approach to the Aesthetics of Myth in Music, Especially That of Wagner, Sibelius and Stravinsky* (The Hague: Mouton Publishers, 1979)
- Taruskin, Richard, *Defining Russia Musically* (Princeton: Princeton University Press, 1997)
- — —, 'On Letting the Music Speak for Itself: Some Reflections on Musicology and Performance', *The Journal of Musicology*, 1 (1982), 338–49
- — —, *Text and Act: Essays on Music and Performance* (NY: Oxford University Press, 1995)
- Teigen, Karl, 'Yerkes-Dodson: A Law for All Seasons', *Theory & Psychology*, 4 (1994), 525–47
- Thompson, Sam, 'Determinants of Listeners' Enjoyment of a Performance', *Psychology of Music*, 35 (2007), 20–36
- Thompson, Sam, Aaron Williamon, 'Evaluating Evaluation: Musical Performance Assessment as a Research Tool', *Music Perception*, 21 (2003), 21–41
- Timmers, Renee, 'Communication of (e)Motion through Performance', *Orbis Musicae*, 14 (2007), 116–40
- — —, 'Vocal Expression in Recorded Performances of Schubert Songs', *Musicae Scientiae*, 11 (2007), 237–68
- Timmers, Renee, Richard Ashley, Peter Desain, Hank Heijink, 'The Influence of Musical Context on Tempo Rubato', *Journal of New Music Research*, 29 (2000), 131–58
- Timmers, Renee, Henkjan Honing, 'On Music Performance, Theories, Measurement and Diversity', *Cognitive Science Quarterly*, 1 (2002), 1–19
- Tipton, Lisa, 'Schoenberg's "Phantasy" Form' (Doctor of Musical Arts dissertation, City University of New York, 2017)
- Tobudic, Asmir, Gerhard Widmer, 'Playing Mozart Phrase by Phrase', in *Proceedings of the 5th International Conference on Case-Based Reasoning* (presented at the 5th International Conference on Case-based Reasoning, Berlin: Springer, 2003), 552–66
- Todd, Neil, 'A Computational Model of Rubato', *Contemporary Music Review*, 3 (1989), 69–88
- — —, 'A Model of Expressive Timing in Tonal Music', *Music Perception*, 3 (1985), 33–58
- — —, 'The Dynamics of Dynamics: A Model of Musical Expression', *Journal of the Acoustical Society of America*, 91 (1992), 3540–50
- — —, 'The Kinematics of Musical Expression', *Journal of the Acoustical Society of America*, 97 (1995), 1940–49
- Todd, Neil, Rosanna Cousins, Christopher Lee, 'The Contribution of Anthropometric Factors to Individual Differences in the Perception of Rhythm', *Empirical Musicology Review*, 2 (2007), 1–13, <http://hdl.handle.net/1811/24478>
- Tougaard, Jakob, Nina Eriksen, 'Analysing Differences among Animal Songs Quantitatively by Means of the Levenshtein Distance Measure', *Behaviour*, 143 (2006), 239–52

- Trainor, Laurel, 'Do Preferred Beat Rate and Entrainment to the Beat Have a Common Origin in Movement?', *Empirical Musicology Review*, 2 (2007), 17–20, <http://hdl.handle.net/1811/24480>
- Traub, Andreas, 'Die "Kinderszenen" Als Zyklisches Werk', *Musica*, 6 (1981), 424–26
- Treitler, Leo, 'History and the Ontology of the Musical Work', *The Journal of Aesthetics and Art Criticism*, 51 (1993), 483–97
- Tsay, Chia-Jung, 'Sight over Sound in the Judgment of Music Performance', ed. Dale Purves, *Proceedings of the National Academy of Sciences*, 119 (2012), 14580–85, <https://doi.org/10.1073/pnas.1221454110>
- Turner, Richard, 'Style and Tradition in String Quartet Performance: A Study of 32 Recordings of Beethoven's Op. 131 Quarter' (PhD dissertation, 2004)
- Tussey, Deborah, 'Music at the Edge of Chaos: A Complex Systems Perspective on File Sharing', *Loyola University Chicago Law Journal*, 37 (2005), 102–67
- Typke, Rainer, Frans Wiering, Remco Veltkamp, 'Mirex Symbolic Melodic Similarity and Query by Singing/Humming' (presented at the MIREX 2006 (at ISMIR 2006), Victoria, BC, 2006)
- Valentine, Elizabeth, 'The Fear of Performance', in *Musical Performance: A Guide to Understanding*, ed. by John Rink (Cambridge University Press, 2002), 168–182, <https://doi.org/10.1017/CBO9780511811739.013>
- Van Zijl, Anemone, Geoff Luck, 'Thoughts in Concert: A Multi-Method Approach to Investigate Effects of Performers' Focus of Attention', in *Proceedings of the International Symposium on Performance Science* (presented at the International Symposium on Performance Science, Vienna: Association Europeene des Conservatoires, 2013), 665–70
- Van Zijl, Anemone, John Sloboda, 'Performers' Experienced Emotions in the Construction of Expressive Musical Performance: An Exploratory Investigation', *Psychology of Music*, 39 (2010), 196–219
- Vempala, Naresh, Frank Russo, 'An Empirically Derived Measure of Melodic Similarity', *Journal of New Music Research*, 44 (2015), 391–404
- Vines, Bradley, Regina Nuzzo, Daniel Levitin, 'Analysing Temporal Dynamics in Music: Differential Calculus, Physics and Functional Data Analysis Techniques', *Music Perception*, 23 (2005), 137–52
- Walker, Timothy, 'Instrumental Differences in Characteristics of Expressive Musical Performance', (PhD dissertation, 2004), Ohio State University
- Wanderley, Marcelo, 'Quantitative Analysis of Non-Obvious Performer Gestures' (presented at the GW 2001 LNAI 2298, Berlin: Springer-Verlag, 2002), 241–53
- Wanderley, Marcelo, Bradley Vines, Neil Middleton, Cory McKay, Wesley Hatch, 'The Musical Significance of Clarinetists' Ancillary Gestures: An Exploration of the Field', *Journal of New Music Research*, 34 (2005), 97–113

- Weisstein, Eric, 'Central Limit Theorem', <http://mathworld.wolfram.com/CentralLimitTheorem.html>, Accessed: 13 August 2013
- Welsh, Borisov, Hill, von Behren, Woo, 'Querying Large Collections of Music for Similarity', *Technical Report UC Berkeley Computer Science Division*, UCB/CSD-00-1096 (2000)
- Welsh, Matt, Nikita Borisov, Jason Hill, Robert von Behren, Alec Woo, *Querying Large Collections of Music for Similarity* (Advanced Research Projects Agency, 1999)
- Westell, Emily, 'Reconsidering Conventional Techniques in the Performance of the Violin Music of the Second Viennese School', Doctor of Musical Performance dissertation, (Schulich School of Music, McGill University, 2011)
- Whittall, Arnold, 'Schoenberg since 1951: Overlapping Opposites', *The Musical Times*, 142 (2001), 11–20
- — —, *The Cambridge Introduction to Serialism*, Cambridge Introductions to Music (New York, 2008)
- — —, 'Twentieth-Century Music in Retrospect: Fulfilment or Betrayal?', *The Musical Times*, 140 (1999), 11–21
- Wicklin, Rick, 'What Is Mahalanobis Distance?', *The Do Loop*, 2012, <https://blogs.sas.com/content/iml/2012/02/15/what-is-mahalanobis-distance.html>, Accessed 15 March 2018]
- Widmer, Gerhard, Simon Dixon, Werner Goebbl, Elias Pampalk, Asmir Tobudic, 'In Search of the Horowitz Factor', *AI Magazine*, 24 (2003), 111–30
- Widmer, Gerhard, Werner Goebbl, 'Computational Models of Expressive Music Performance: The State of the Art', *Journal of New Music Research*, 33 (2004), 203–16
- Williamon, Aaron, Daniela Coimbra, eds., *Proceedings of the International Symposium on Performance Science 2007* (Brussels: European Association of Conservatoires (AEC), 2007)
- Williamon, Aaron, Jane Davidson, 'Exploring Co-Performer Communication', *Musicae Scientiae*, 6 (2002), 53–72
- Williamon, Aaron, Werner Goebbl, eds., *Proceedings of the International Symposium on Performance Science 2013* (Brussels: European Association of Conservatoires (AEC), 2013)
- Williamon, Aaron, Masanobu Miura, eds., *Abstracts of the International Symposium on Performance Science 2015* (Kyoto: Ryukoku University, 2015)
- — —, eds., *Proceedings of the International Symposium on Performance Science 2015* (Kyoto, Japan: Ryokoku University, 2015)
- Williamon, Aaron, Elizabeth Valentine, John Valentine, 'Shifting the Focus of Attention between Levels of Musical Structure', *European Journal of Cognitive Psychology*, 14 (2002), 493–520
- Wintle, Christopher, 'Analysis and Performance: Webern's Concerto Op.24/II', *Music Analysis*, 1 (1982), 73–99

- Worthington, Emily, 'The Modernisation of Wind Playing in London Orchestras, 1909-1939: A Study of Playing Style in Early Orchestral Recordings.' (PhD Dissertation, University of York, 2013)
- Yan, Xin, Xiao Su, *Linear Regression Analysis: Theory and Computing* (Hackensack, NJ: World Scientific Publishing, 2009)
- Yang, Kiyong, Cyrus Shahabi, 'A PCA-Based Similarity Measure for Multivariate Time Series', in *Proceedings of the 2nd ACM International Workshop on Multimedia Databases* (presented at the MMDDB '04, ACM, 2004), 65–74, <https://doi.org/http://dx.doi.org/10.1145/1032604.1032616>
- — —, 'An Efficient k Nearest Neighbor Search for Multivariate Time Series', *Information and Computation*, 205 (2007), 66–98
- Young, James, Carl Matheson, 'The Metaphysics of Jazz', *The Journal of Aesthetics and Art Criticism*, 58 (2000), 125–33
- Young, Robert, 'Inharmonicity of Plain Wire Piano Strings', *The Journal of the Acoustical Society of America*, 24 (1952), 267–73, <https://doi.org/http://dx.doi.org/10.1121/1.1906888>
- Zak, Albin, 'The Art of Record Production', *Journal on the Art of Record Production*, 2007, <http://www.arpjournal.com/asarpwp/the-art-of-record-production/>, Accessed: 21 February 2017
- — —, 'The State of The Art and The State of The Discipline', *Journal on the Art of Record Production*, 06 (2012)
- Zbikowski, Lawrence, 'Musical Coherence, Motive, Categorization', *Music Perception*, 17 (1999), 5–42
- Zhang, Q, Eduardo Miranda, 'Evolving Expressive Music Performance through Interaction of Artificial Agent Performers', in *Proceedings of the ECAL Workshop on Music and Artificial Life* (presented at the ECAL Workshop on Music and Artificial Life, Lisbon: MusicAL, 2007)

# Discography of Schoenberg *Phantasy* Op.47

Note: where 2 years are shown, the first is the issue date and the second the recording date.

- Allen, Jenny, Anita Murray, Michael Noad, Rebecca Dunlop, and Ellen Garland, 'Using Self-Organizing Maps to Classify Humpback Whale Song Units and Quantify Their Similarity', *Journal of the Acoustical Society of America*, 142 (2017), <https://doi.org/https://doi.org/10.1121/1.4982040>
- Anderegg, Francesca and Funderburk, Brett. (Albany Music Distribution TROY1361 (2012), 2012)
- Arditti, Irvine and Litwin, Stefan. (Berlin: Auvidis Montaigne MO 782025 (1995), 1994)
- Baker, Israel and Gould, Glenn. (Sony Classical B009TB1IAW (2012), 1964)
- Bellini, Stefano and Giannotti, Reiko. (Conservatory of Parma, 2004),  
<https://www.youtube.com/watch?v=FbpoAVVvDNk>, Accessed: 8 January 2014
- Borup, Hasse and Ernst, Mary. (Centaur CRC 2918 (2008), 2008)
- Bress Hyman and Reiner, Charles. (Folkways FM 3354, 1962)
- Colbentson, Oliver and Appel, Erich. (Live recording, 2010),  
[https://www.youtube.com/watch?v=y\\_YdRf8Q7cQ](https://www.youtube.com/watch?v=y_YdRf8Q7cQ), Accessed: 10 January 2014
- David, Wolfgang and Gompfer, David. (VDE-GALLO (2012), 2012)
- Degand, Stephanie-Marie and Peyrebrune, Olivier. (Live self-published, 2013),  
<https://www.youtube.com/watch?v=GfB8gKGVAQY>, Accessed: 10 January 2014
- Doll, Barbara and Marton, Christina. (ArcoDiva (2012), 2012)
- Felberg, David and Gordon, Judith. (Live self-published, 2013),  
<https://www.youtube.com/watch?v=GfB8gKGVAQY>, Accessed: 10 January 2014
- Frayonova, Liudmila and Pashchenko, Olga. 2008, <https://www.youtube.com/watch?v=dn8DNhunZKE>,  
Accessed: 15 January 2016
- Fukuhara, Mayuki and Roden, Chie Sato. *Phantasy Op. 47* (self-published 2011, 2011)
- Goldberg, Szymon and Webster, Beveridge. (Music and Arts Programs of America (2013) iTunes, 1966)
- Gotkovsky, Nell and Gotkovsky, Ivar. (Paris: RCA RL 37090 (1980), 1976)
- Gross, Robert and Grayson, Richard. (Orion ORS 74147 (1974), 1974)
- Huang, Frank and Vainstein, Dina. (King City, Ontario: Naxos 8.557121 (2003), 2002)
- Israelivitch, Jacques and Lemelin, Stéphane. (Fleur de Son Classics FDS 57941 (2000), 2000)
- Kagan, Oleg and Liubimov, Aleksei. (Melodiia 33S10-06717/18 (1978), 1978)
- Kim, Helen and Bowles, Adam. 2004, <http://www.lunanova.org/audio.html>, Accessed: 10 January 2014
- Koh, Jennifer and Uchida, Reiko. (New York: Cedille CDR 90000 073 (2004), 2003)

Koldofsky, Adolf and Steuermann, Eduard. (DIAL DLP 14, 1951)

Kolisch, Rudolf and Johansen, Gunnar. (Wisconsin: live tape from Werner Unger, 1965)

Kolisch, Rudolf and Johansen, Gunnar. (Wisconsin: live tape from Werner Unger, 1966)

Kolisch, Rudolf and Stock, Else. (Darmstadt: Archiphon WU-045 (2005), 1953)

Kolisch, Rudolf and Willmann, Alan. (Audite 21.412 (2012), 1953)

Kolisch, Rudolf and Willmann, Alan. (Tape from Werner Unger, probably German radio recording, 1954)

Kremer, Gidon and Maisenberg, Oleg. (Deutsche Grammophon 447 112-2 GH (1995), 1994)

Lang, Brigitte and Lang, Yvonne. (Sion, Switzerland: Claves CD 50-2005 (2000), 2000)

van der Meer, Janneke and Grotenhuis, Sepp. (Utrecht: Chandos CHAN 9939 (2001), 2001)

Menuhin, Yehudi and Gould, Glenn. (Toronto: Sony Classical SM4K 62364 (1996), 1965)

Möller, Daniel and Öquist, Georg. (Live 2010, 2010), <https://www.youtube.com/watch?v=6-hfmc8v5KI>, Accessed: 10 January 2014

Repin, Vadim and Lugansky, Nikolai. (Tokyo: Live recording, 2004), [https://www.google.ie/search?q=repin+lugansky+phantasy&ie=utf-8&oe=utf-8&rls=org.mozilla:en-US:official&client=firefox-a&channel=fflb&gws\\_rd=cr&ei=IWROVMuNGIWs7AbWkYCoCA](https://www.google.ie/search?q=repin+lugansky+phantasy&ie=utf-8&oe=utf-8&rls=org.mozilla:en-US:official&client=firefox-a&channel=fflb&gws_rd=cr&ei=IWROVMuNGIWs7AbWkYCoCA), Accessed: 10 January 2014

Revich, Elena and Kholodenko, Vadim. (Live 2010, 2010), <https://www.youtube.com/watch?v=cpRsNInudt4>, Accessed: 17 January 2017

Schulte, Rolf and Oldfather, Christopher. (Naxos 8557533, 2010)

Soltau, Sara and Auvil, Richard. (2011), self-published at <https://www.youtube.com/watch?v=WWeF4S4RK0Y>, Accessed: 15 January 2019

Swenson, Lucille and Chung, Ian. (Music@Menlo 2011), [https://www.youtube.com/watch?v=1\\_LRcAXPVNI](https://www.youtube.com/watch?v=1_LRcAXPVNI), Accessed: 17 January 2017

VanDerMeer, Janneke and Grotenhuis, Sepp. (Chandos CHAN9939, 2001)

Varga, Tibor and Krenek, Ernst. (Berlin: Audite 21.412 (2012), 1951)

Veselka, Frantisek and Dratková, Milena. (Høvikodden, near Oslo: Simax PS 1026 (1987), 1985)

Walch, Martin and Körber, Till. (Vienna: Preiser 90565 (2003), 2001)

Wallin, Ulf and Pontinnen, Roland. (Stockholm: Bis CD-1407 (2005), 2001)

Widmann, Carolin and Lepper, Simon. (ECM New Series (2009), 2009)

Yamada, Kaoru and Kynoch, Sholto. (Stone Records (Classical) (2010), 2010)

# Appendix A. Sample Dissimilarity Matrices<sup>1</sup>

*Phantasy* (complete performances, combined tempo and dynamics)

	PN	Koldofsky-Steuermann51	Varga-Krenek51	Kolisch-Stoek53	Kolisch-Willmann53	Bress-Reiner62	Baker-Gould64	Kolisch-Johansen65	Menuhin-Gould65	Goldberg-Webster66	Kolisch-Johansen66	Gross-Grayson74	Gotkovsky-Gotkovsky76	Kremer-Malsenber77	Kagan-Lobanov78	Veselka-Dratvova85	Arndt-Litwin94	Kremer-Malsenber94	Israelievitch-Lemelin00	Lang-Lang00	VanDerMeer-Grotenhuijs01	Walch-Korber01	Wallin-Pontinen01	Huang-Vainstein02	Koh-Uchida03	Bellini-Gianotti04	Repin-Lugansky04	Doll-Martono5	Borup-Ernst06	Widmann-Lepper06	Frayanova-Pashchenko08	Colbentson-Appel10	Moller-Oquist10	Reich-Kolodenko10	Schulte-Oldfather10	Yamada-Kynch10	Anderegg-Funderburk11	Fukuhara-Roden11	David-Gompper12	Soltau-Auviel12	Swenson-Chung12	Degand-Peyrebrune13	Felberg-Gordon13				
PN	0.0	13.9	14.2	12.2	14.1	12.3	15.5	15.1	13.9	15.7	12.6	13.9	13.7	13.8	14.3	14.4	13.9	13.6	13.2	13.5	14.0	13.3	13.1	13.2	13.9	13.7	14.1	13.0	13.9	13.6	14.5	14.0	15.4	13.5	13.6	13.5	13.3	14.0	13.5	13.8	13.3	13.7	14.4	13.6	14.0		
Koldofsky-Steuermann51	13.9	0.0	4.8	7.0	4.0	3.9	4.5	4.7	4.4	5.6	5.5	4.0	3.4	4.6	4.2	4.7	3.7	4.2	4.4	3.5	4.3	5.2	4.7	3.8	4.9	4.0	4.8	5.8	5.0	3.8	4.1	4.2	4.4	5.4	3.8	5.9	3.8	4.3	4.2	4.5	5.9	3.9	4.9	4.8	4.1		
Varga-Krenek51	14.2	4.8	0.0	7.4	5.4	4.9	4.3	4.6	4.8	6.1	5.3	5.0	4.5	5.8	4.9	4.6	4.5	4.0	4.8	4.1	5.0	4.8	5.1	4.4	4.6	4.2	5.3	4.2	4.7	3.8	4.8	4.8	5.5	4.6	4.6	6.7	4.3	5.0	4.7	4.5	7.0	4.4	5.5	5.5	4.2		
Kolisch-Stoek53	12.2	7.0	7.4	0.0	6.1	6.5	8.6	8.2	6.7	8.4	7.8	7.4	7.7	7.8	7.1	7.0	6.7	6.7	7.0	6.7	7.0	6.7	6.6	6.9	6.9	7.2	7.8	7.1	8.2	6.5	7.3	7.6	7.8	6.3	7.4	8.4	6.6	7.4	7.1	7.7	7.1	7.4	7.8	7.3	8.1		
Kolisch-Willmann53	14.1	4.0	5.4	6.1	0.0	3.4	6.1	5.4	4.1	6.3	6.8	3.6	6.0	7.5	5.3	5.9	5.2	5.9	5.3	5.8	6.0	5.3	5.5	5.7	5.9	5.7	6.1	6.4	4.7	5.5	5.5	6.0	6.0	5.7	6.6	5.0	5.2	5.6	6.5	6.8	5.1	5.4	6.2	6.2			
Kolisch-Willmann54	12.3	3.9	4.9	6.5	3.4	0.0	6.4	5.3	3.5	5.8	5.5	2.9	5.6	6.0	4.7	4.7	4.0	4.9	4.2	5.0	5.1	4.5	4.9	4.8	5.0	4.5	5.1	4.7	5.3	4.4	4.5	4.1	5.6	5.4	4.3	5.8	3.9	4.6	4.6	4.8	5.6	3.5	4.5	5.2	4.6		
Bress-Reiner62	15.5	4.5	4.3	8.6	6.1	6.4	0.0	3.7	5.9	4.8	6.6	6.5	5.4	6.6	5.3	5.8	5.5	4.2	4.9	4.5	5.8	5.9	5.8	4.5	5.6	4.6	5.9	6.4	6.7	4.4	4.5	4.9	5.3	5.4	4.7	7.0	4.8	5.9	6.0	5.2	7.1	5.0	5.6	5.5	4.9		
Baker-Gould64	15.1	4.7	4.6	8.2	5.4	5.3	3.7	0.0	5.2	3.2	6.3	5.2	5.2	5.8	4.0	5.0	4.7	3.8	4.5	4.3	4.4	4.8	4.7	6.0	5.4	4.5	3.8	5.2	4.6	5.1	4.1	5.1	4.2	5.9	4.3	5.3	6.6	4.3	5.6	5.1	5.8	4.8	4.4	5.2	4.6	5.3	
Kolisch-Johansen65	13.9	4.4	4.8	6.7	4.1	3.5	5.9	5.2	0.0	6.4	6.4	3.7	4.2	6.6	4.8	4.3	4.7	4.4	4.4	4.8	4.8	4.7	6.0	5.4	4.5	3.8	5.2	4.6	5.1	4.1	5.1	4.2	5.9	4.3	5.3	6.6	4.3	5.6	5.1	5.8	4.8	4.4	5.2	4.6	5.3		
Menuhin-Gould65	15.7	5.6	6.1	8.4	6.3	5.8	4.8	3.2	6.4	0.0	6.9	6.4	6.6	6.4	6.2	6.4	5.6	5.7	6.1	5.9	6.2	6.1	5.8	5.4	6.9	5.8	6.2	6.7	6.6	5.6	3.9	5.3	5.8	6.6	4.5	7.0	5.8	5.9	6.3	6.3	7.2	5.4	5.2	6.4	6.0		
Goldberg-Webster66	12.6	5.5	5.3	7.8	6.8	5.5	6.6	6.3	6.4	6.9	0.0	5.6	4.8	5.3	5.9	5.1	5.4	4.9	4.9	5.1	5.4	4.9	5.1	5.0	4.4	4.4	5.1	5.1	5.9	5.3	4.5	5.4	5.8	5.3	7.2	6.2	4.4	5.3	5.0	4.8	5.2	4.8	6.7	4.9	5.1	5.8	4.8
Kolisch-Johansen66	13.9	4.0	5.0	7.4	3.6	2.9	6.5	5.2	3.7	6.4	5.6	0.0	5.1	6.6	4.6	5.0	4.7	4.8	4.8	5.0	4.9	4.4	5.0	4.5	4.8	5.1	5.0	5.1	4.9	4.7	4.5	6.0	5.6	4.8	6.0	4.3	4.6	4.6	5.7	6.4	4.7	4.6	5.4	4.8			
Gross-Grayson74	13.7	3.4	4.5	7.7	6.0	5.6	5.4	5.2	4.2	6.6	4.8	5.1	0.0	5.5	5.5	4.9	4.2	4.2	4.4	3.4	4.9	4.1	5.7	4.3	4.0	3.9	4.7	4.6	5.1	4.6	5.2	4.5	5.4	5.3	4.4	5.0	4.7	4.4	4.3	4.1	6.2	4.0	4.8	4.7	4.0		
Gotkovsky-Gotkovsky76	13.8	4.6	5.8	7.8	7.5	6.0	6.6	5.8	6.6	6.4	5.3	6.6	5.5	0.0	5.6	5.7	5.3	6.0	5.0	5.2	5.7	5.5	5.0	5.0	4.8	5.7	5.4	6.3	4.9	5.1	5.7	5.3	6.5	6.3	4.0	6.6	5.3	5.0	5.0	5.6	6.2	5.0	6.5	4.8	4.2		
Kremer-Malsenber77	14.3	4.2	4.9	7.1	5.3	4.7	5.3	4.0	4.8	6.2	5.9	4.6	5.5	5.6	0.0	3.5	3.3	4.2	3.6	4.2	3.9	3.6	4.6	3.5	3.6	3.2	4.7	3.3	3.8	4.2	4.0	3.6	5.5	3.7	3.9	5.6	3.4	4.0	4.0	4.1	4.9	3.8	4.5	4.9	3.7		
Kagan-Lobanov78	14.4	4.7	4.6	7.0	5.9	4.7	5.8	5.0	4.3	6.4	5.9	5.0	4.9	5.7	3.5	0.0	2.4	4.1	3.0	4.7	3.8	3.8	4.7	3.8	3.2	3.2	5.2	4.2	4.1	3.6	4.5	3.4	5.2	4.4	4.3	5.7	3.8	3.5	4.2	4.3	3.2	4.0	4.8	4.6			
Veselka-Dratvova85	13.9	3.7	4.5	6.7	5.2	4.0	5.5	4.7	4.7	5.6	5.1	4.7	4.2	5.3	3.3	2.4	0.0	3.5	3.3	3.6	3.6	3.6	3.3	2.5	3.0	3.8	4.3	4.0	3.0	3.4	3.5	4.6	4.1	3.8	3.9	3.4	2.6	3.0	4.2	4.9	3.2	4.0	4.2	3.2			
Arndt-Litwin94	13.6	4.2	4.0	6.7	5.9	4.9	4.2	3.8	4.4	5.7	5.4	4.8	4.2	6.0	4.2	4.1	3.5	0.0	3.7	2.8	3.8	4.2	3.9	3.2	3.6	2.8	5.0	3.5	3.5	3.0	4.0	3.8	3.9	2.8	3.7	6.2	3.5	3.8	3.9	3.4	5.6	3.5	4.5	4.3	3.8		
Kremer-Malsenber94	13.2	4.4	4.8	7.0	5.3	4.2	4.9	4.5	4.4	6.1	4.9	4.8	4.4	5.0	3.6	3.0	3.3	3.7	0.0	3.3	4.0	3.6	3.8	3.5	3.6	3.0	4.5	4.0	3.5	3.7	4.3	3.3	3.7	3.7	3.9	5.0	3.1	3.8	3.5	3.6	4.6	2.8	4.8	3.7	4.1		
Israelievitch-Lemelin00	13.5	3.5	4.1	6.7	5.8	5.0	4.5	4.3	4.8	5.9	4.9	5.0	3.4	5.2	4.2	4.7	3.6	2.8	3.3	0.0	3.9	4.0	4.1	4.0	3.5	3.5	4.1	4.6	3.7	3.4	4.0	4.0	3.3	3.5	3.1	5.5	3.3	4.0	3.0	3.5	4.0	5.0	4.4	3.7			
Lang-Lang00	14.0	4.3	5.0	7.0	6.0	5.1	5.8	4.4	4.8	6.2	5.1	4.9	4.9	5.7	3.9	3.8	3.6	3.8	4.0	3.9	0.0	4.5	4.5	3.6	3.7	3.6	4.3	5.0	4.4	4.0	4.1	4.0	4.7	4.5	4.3	5.0	3.8	4.3	3.7	4.2	4.8	4.2	4.9	4.3	4.4		
VanDerMeer-Grotenhuijs01	13.3	5.2	4.8	6.7	5.3	4.5	5.9	4.8	4.7	6.1	5.4	4.4	5.1	5.5	3.6	3.8	3.6	4.2	3.6	4.0	4.5	0.0	4.1	3.5	3.8	3.1	5.0	4.6	3.7	4.4	3.5	3.9	5.7	3.2	3.9	5.1	3.9	4.3	3.7	4.3	5.7	3.7	4.9	4.2			
Walch-Korber01	13.1	4.7	5.1	6.6	5.5	4.9	5.8	5.4	6.0	5.8	6.0	5.0	5.7	5.0	4.6	4.7	3.6	3.9	3.8	4.1	4.5	4.1	0.0	4.0	4.5	4.3	5.5	4.6	4.5	3.7	4.8	4.9	5.2	4.6	3.0	5.9	3.7	3.1	3.8	4.4	6.2	4.5	5.4	5.2	4.4		
Wallin-Pontinen01	13.2	3.8	4.4	6.9	5.7	4.8	4.5	4.4	5.4	5.4	4.4	5.0	4.3	5.0	3.5	3.8	3.3	3.2	3.5	4.0	3.6	3.5	4.0	0.0	3.5	3.1	5.3	5.1	3.5	3.8	3.7	3.5	4.8	4.2	2.9	5.6	3.5	3.3	3.7	3.1	5.5	3.6	5.0	4.8	3.2		
Huang-Vainstein02	13.9	4.9	4.6	6.9	5.9	5.0	5.6	4.7	4.5	6.9	4.4	4.5	4.0	4.8	3.6	3.2	2.5	3.6	3.6	3.5	3.7	3.8	4.5	3.5	0.0	3.2	3.9	4.0	3.8	3.7	4.6	3.1	5.4	4.5	4.6	3.3	4.1	4.2	3.3	4.2	5.2	3.2	4.3	4.9	3.6		
Koh-Uchida03	13.7	4.0	4.2	7.2	5.7	4.5	4.6	3.6	3.8	5.8	5.1	4.8	3.9	5.7	3.2	3.2	3.0	2.8	3.0	3.5	3.6	3.1	4.3	3.1	3.2	0.0	4.6	3.6	3.7	3.5	4.0	3.0	4.8	3.2	3.7	4.7	3.3	3.8	3.5	3.0	5.2	2.8	4.3	4.9	3.2		
Bellini-Gianotti04	14.1	4.8	5.3	7.8	5.7	5.1	5.9	5.1	5.2	6.2	5.9	5.1	4.7	5.4	4.7	5.2	3.8	5.0	4.5	4.1	4.3	5.0	5.5	5.3	3.9	4.6	0.0	5.0	4.9	4.5	4.2	4.0	4.9	5.5	4.7	4.9	5.1	4.7	3.7	5.1	5.6	3.7	5.3	4.5	4.5		
Repin-Lugansky04	13.0	5.8	4.2	7.1	6.1	4.7	6.4	5.3	4.6	6.7	5.3	5.0	4.6	6.3	5.3	4.2	4.3	3.5	4.0	4.6	5.0	4.6	5.1	4.0	3.6	5.0	0.0	4.0	3.6	5.4	4.8	5.0	4.7	4.1	5.8	4.1	4.7	5.3	3.9	5.8	3.6	5.3	5.0	4.3			
Doll-Martono5	13.9	5.0	4.7	8.2	6.4	5.3	6.7	5.1	5.1	6.6	4.5	5.1	5.1	4.9	3.8	4.1	4.0	3.5	3.5	3.7	4.4	3.7	4.5	3.5	3.8	3.7	4.9	4.0	0.0	3.6	4.8	3.7	5.3	3.9	3.7	5.4	4.2	4.1	4.1	4.1	5.5	4.1	5.0	4.0	3.5		
Borup-Ernst06	14.5	4.1	4.8	7.3	5.5	4.5	4.5	3.5	5.1	3.9	5.8	4.7	5.2	5.7	4.0	4.5	3.4	4.0	4.3	4.0	4.1	3.5	4.8	3.7	4.6	4.0	4.2	5.4	4.8	4.3	0.0	3.1	4.6	4.7	3.4	5.3	3.8	4.4	3.9	4.9	5.9	4.1	5.3	4.7	4.2		
Widmann-Lepper06	14.0	4.2	4.8	7.6	5.5	4.1	4.9	3.8	4.2	5.3	5.3	4.5	4.5	5.3	3.6	3.4	3.5	3.8	3.3	4.0	4.0	3.9	4.9	3.5	3.1	3.0	4.0	4.8	3.7	3.7	3.1	0.0	4.2	4.2	3.8	4.9	3.9	4.3	4.0	4.2	4.7	3.1	4.4	4.3	4.1		

*Phantasy* (complete performances, combined acceleration and dynamics change rates)

	PN	Kodský-Steuernam51	Varga-Krenek51	Kolisch-Sock33	Kolisch-Willmann53	Kolisch-Willmann54	Blass-Fahne92	Baker-Gould54	Kolisch-Johannes5	Mennulin-Gould55	Golding-Webster66	Kolisch-Johannes6	Gross-Grayton74	Gotsky-Gotsky78	Kramer-Malsenb77	Kagan-Malsenb78	Vonka-Draevnos	Adlitz-Ustina	Kramer-Malsenb84	Izraelentich-Lemeln00	Larg-Lango20	Vard-Mker-Groshen001	Witch-Korbozt1	Willis-Pontinn01	Hung-Vonstinn02	Koh-Uchidok3	Bellini-Gamot04	Kin-Bowleg4	Repin-Lugansk04	Dolt-Morton5	Boup-Ernst06	Widmann-Lapper06	Fraynau-Pashchenko8	Colbentson-Angelo10	Mellic-Quetio10	Rach-Koldenko10	Schults-Oldfether10	Yamaoka-Kynch10	Andreev-Funkelburk11	Fukuhara-Roden11	Soltau-Gamper12	Soviet-Avulit12	Sveens-Chung12	Dogard-Peyrubrun13	Felberg-Gordon13	
PN	0.00	4.83	4.03	5.59	4.42	5.67	5.09	4.10	5.06	4.65	4.83	4.91	4.81	5.29	4.81	4.84	4.91	4.47	4.28	3.81	4.84	4.54	5.04	4.04	4.73	5.39	4.93	4.88	5.13	5.02	4.84	4.29	4.90	4.67	4.63	4.75	5.02	4.21	4.78	4.72	4.77	4.52	5.01	4.77	4.31	
Kodský-Steuernam51	4.83	0.00	2.58	4.53	2.88	1.66	3.99	1.12	1.98	3.20	2.38	3.07	3.04	2.62	2.02	2.38	2.95	1.81	2.82	2.74	2.21	3.25	2.75	2.20	2.91	2.78	2.01	2.38	3.34	2.67	2.86	3.61	4.29	4.70	4.13	2.36	4.03	3.61	4.20	3.78	2.23	2.84	2.04	2.65	3.63	2.74
Varga-Krenek51	4.03	2.58	0.00	4.85	2.84	1.66	3.99	3.34	3.32	2.25	2.20	3.24	2.70	2.93	2.64	2.29	3.14	2.84	3.56	2.86	2.63	3.39	4.07	3.23	2.52	3.56	2.57	2.75	4.04	3.88	3.87	3.15	4.29	4.78	3.02	4.56	3.85	3.50	3.37	3.12	2.96	2.46	2.85	3.88	2.44	
Kolisch-Sock33	5.59	4.53	4.85	0.00	4.06	4.17	5.12	4.83	4.92	4.61	4.27	4.17	4.79	3.96	3.71	4.71	4.68	4.70	5.03	4.33	4.56	4.70	4.61	3.77	4.41	4.78	4.35	4.85	4.82	4.58	4.44	3.81	4.70	5.34	4.30	4.94	4.81	4.55	4.36	4.40	3.94	4.30	4.95	4.55	4.65	
Kolisch-Willmann53	4.42	2.88	2.84	4.06	0.00	2.65	2.98	2.21	1.80	2.80	3.37	1.84	3.51	2.88	2.78	1.58	2.88	3.84	3.40	2.86	2.59	2.88	3.40	2.86	2.59	2.99	2.61	3.82	3.38	2.76	2.51	2.34	2.68	2.99	2.52	2.95	3.51	2.41	2.65	3.41	3.23	2.49	3.44	3.94	3.12	
Kolisch-Willmann54	5.67	1.66	2.86	4.17	2.65	0.00	3.97	3.30	2.44	3.35	2.15	2.89	2.65	2.97	2.67	2.16	2.46	1.97	2.67	2.92	2.40	2.87	3.41	2.16	3.16	2.94	1.95	2.73	3.24	2.94	2.56	3.03	2.46	3.06	2.53	2.78	4.44	2.37	2.61	2.45	2.00	1.67	2.51	2.98	2.33	
Blass-Fahne92	5.09	3.99	4.06	5.12	2.98	3.97	0.00	3.07	3.72	4.40	4.53	2.62	4.19	4.17	3.26	3.85	3.81	4.19	3.35	2.55	4.51	3.48	3.82	3.86	2.89	4.21	3.60	4.88	4.87	4.02	2.93	2.45	3.83	3.62	3.68	3.77	3.17	3.52	3.64	4.31	4.57	3.99	3.77	4.02	3.77	
Baker-Gould54	4.10	3.12	3.34	4.83	2.21	3.30	3.07	0.00	2.80	2.41	4.24	2.22	3.64	3.54	3.30	2.90	2.97	3.56	2.71	2.94	2.87	3.32	3.14	2.80	2.47	3.23	2.67	4.03	3.98	3.13	3.24	2.59	3.38	3.32	3.80	3.37	3.28	3.58	3.53	3.69	3.87	3.06	3.37	3.78		
Kolisch-Johannes5	5.06	1.98	3.32	4.92	1.81	2.44	3.72	2.80	0.00	3.23	4.21	2.31	3.45	4.02	3.86	2.84	2.47	3.07	2.60	2.21	2.32	2.39	3.95	3.08	2.15	2.76	3.00	4.07	3.59	3.50	2.71	2.54	3.27	2.71	1.90	3.34	3.98	2.64	2.59	3.18	3.03	3.71	3.26	4.19	2.91	
Mennulin-Gould55	4.65	3.20	3.25	4.61	2.80	3.33	3.40	2.41	3.23	0.00	2.79	2.68	3.78	3.17	3.24	3.49	2.94	3.87	3.13	3.42	4.07	3.05	4.16	3.58	3.39	3.51	3.32	3.67	3.85	3.29	3.03	2.47	3.03	3.27	2.85	3.74	3.66	2.80	3.67	3.80	2.91	3.59	3.87	3.40		
Golding-Webster66	4.83	2.38	2.20	4.67	3.33	2.15	4.53	4.24	3.42	3.79	0.00	3.58	2.60	3.12	2.97	3.12	3.09	2.32	3.17	3.22	3.07	4.10	4.27	3.02	3.03	3.06	2.48	2.25	3.61	3.29	3.74	3.62	3.63	3.96	3.26	4.34	3.87	3.42	2.28	2.64	2.45	2.84	3.51	2.61		
Kolisch-Johannes6	4.91	3.07	3.24	4.17	1.84	2.89	2.62	3.22	2.21	2.28	3.58	0.00	3.64	3.36	2.77	1.72	2.05	2.97	2.36	3.12	3.25	3.72	3.21	4.25	2.24	2.71	2.22	3.70	3.60	2.98	2.90	1.86	2.82	3.51	1.81	2.98	2.93	3.24	2.65	3.08	4.09	2.85	3.02	3.81	2.17	
Gross-Grayton74	4.81	3.04	3.74	4.79	3.11	2.65	4.18	3.64	3.45	3.78	2.60	3.64	0.00	3.15	3.08	3.31	3.22	2.70	3.42	2.68	3.07	3.46	4.32	3.23	2.76	3.39	3.50	3.28	3.38	2.36	3.49	3.37	2.91	4.13	3.34	3.46	3.94	3.25	3.05	2.88	2.76	3.26	3.85	3.63	2.73	
Gotsky-Gotsky78	5.29	2.62	3.93	3.96	2.88	2.96	4.17	3.54	4.02	3.17	3.12	3.36	3.15	0.00	3.75	3.51	3.56	3.06	2.93	3.11	3.59	3.89	3.72	2.80	3.42	3.60	3.05	3.64	3.07	2.78	3.20	3.25	3.51	3.91	3.54	4.33	3.39	3.36	3.68	3.31	3.51	3.13	2.99	4.49	3.06	
Kramer-Malsenb77	4.81	2.02	2.64	4.47	2.78	2.07	3.26	3.33	2.59	3.24	2.97	2.77	3.08	3.75	0.00	2.23	2.44	2.60	2.92	2.46	2.45	2.55	3.60	2.20	2.40	2.56	3.03	3.43	3.05	3.12	2.16	2.60	2.74	3.65	2.54	3.98	2.93	3.31	2.24	2.49	2.90	3.14	2.99	4.10	2.47	
Kagan-Malsenb78	4.84	2.38	2.29	4.17	1.58	2.16	3.85	2.90	1.84	3.49	3.12	1.72	3.31	3.51	2.23	0.00	2.60	1.98	2.30	2.03	1.50	2.60	3.61	2.71	2.57	2.58	2.23	3.80	3.14	2.18	2.73	2.70	2.77	2.40	1.76	3.78	3.18	2.32	2.54	2.49	2.63	2.04	2.57	3.38	2.39	
Vonka-Draevnos	4.91	2.95	3.14	4.68	2.42	2.46	3.81	2.97	2.47	2.94	3.09	2.05	3.32	3.56	2.44	2.47	0.00	2.38	2.09	1.73	2.14	2.47	2.60	2.38	2.09	1.73	2.41	2.31	3.86	3.27	2.33	2.32	2.07	2.40	2.79	1.77	3.68	3.12	2.84	1.36	2.82	3.06	2.62	2.98	3.38	2.56
Adlitz-Ustina	4.47	2.81	2.58	4.70	2.73	1.97	4.19	3.56	3.07	3.87	2.32	2.97	2.70	3.06	2.60	1.98	2.38	0.00	2.40	2.30	1.33	3.00	3.09	1.62	1.71	2.53	2.89	3.77	3.18	1.88	2.70	3.06	2.69	2.82	2.44	3.82	2.37	2.04	2.16	1.77	2.40	1.79	2.44	3.78	2.83	
Kramer-Malsenb84	4.28	2.82	3.56	5.03	2.98	2.67	3.35	2.71	2.60	3.13	2.17	2.36	3.42	3.03	2.92	3.20	2.09	2.40	0.00	1.91	2.37	3.10	3.09	2.51	2.35	2.97	2.89	3.85	2.75	2.55	2.14	2.55	2.91	2.77	2.37	2.75	2.96	2.14	2.34	2.69	3.18	2.70	2.56	2.89	2.76	
Izraelentich-Lemeln00	3.81	2.74	2.86	4.33	1.88	2.92	2.55	1.76	2.21	2.42	3.32	1.68	3.11	2.46	2.03	1.73	2.30	1.91	0.00	2.26	2.48	2.78	2.59	1.63	3.32	2.55	3.69	3.52	2.21	2.24	2.33	2.02	1.95	1.43	2.14	2.50	2.00	1.94	3.24	3.19	2.97	3.06	3.33	2.23		
Larg-Lango20	4.84	2.21	3.63	4.56	2.88	2.40	4.51	3.24	2.32	3.47	2.07	2.75	3.07	3.59	2.45	1.50	2.14	1.33	2.97	2.26	0.00	2.85	3.42	2.90	1.80	2.70	1.78	3.44	3.59	2.99	2.89	2.18	2.90	2.71	1.92	4.13	3.85	2.56	1.87	2.41	2.89	2.21	2.75	4.13	2.44	
Ward-Mker-Groshen001	4.54	3.12	3.85	4.49	3.24	3.12	3.34	3.33	3.09	3.05	3.28	3.05	3.28	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	
Witch-Korbozt1	5.04	3.75	4.07	6.10	3.40	3.41	4.74	3.74	3.95	4.16	4.27	3.91	4.32	3.72	3.60	3.61	2.60	3.09	2.99	2.78	4.42	3.42	3.00	3.61	3.59	3.36	3.02	4.64	4.60	3.38	3.61	3.19	3.77	2.80	3.16	3.19	3.17	3.20	3.16	3.24	3.65	3.69	4.40	4.03	4.27	
Willis-Pontinn01	4.04	3.20	3.23	3.77	2.86	2.16	3.86	3.08	3.58	3.02	2.75	3.23	3.20	3.60	2.71	2.38	1.62	2.51	2.59	2.39	2.79	3.61	0.00	2.46	2.68	2.26	2.89	3.29	3.24	2.33	2.19	3.49	3.10	2.72	3.30	3.66	3.30	2.10	2.27	2.23	2.86	1.77	3.32	3.77		
Hung-Vonstinn02	4.73	2.91	2.52	4.41	2.59	3.16	2.89	2.47	3.15	3.39	3.03	2.24	2.76	3.42	2.20	2.57	2.11	1.75	2.35	1.63	1.80	3.01	3.59	2.46	0.00	3.32	3.11	3.44	3.35	2.60	2.57	1.75	2.71	2.70	3.21	3.12	3.26	2.89	2.52	2.00	2.67	3.31	2.65	3.73	3.61	2.09
Koh-Uchidok3	5.39	2.78	3.56	4.78	2.98	1.94	4.21	3.13	2.76	3.51	3.06	2.71	3.39	3.60	2.56	2.58	2.49	2.53	2.97	3.32	3.70	3.42	3.36	2.68	3.32	0.00	2.63	3.52	3.68	2.53	3.21	3.78	3.28	3.82	2.84	3.64	2.45	2.53	2.52	3.05	2.06	2.48	3.84	3.29		
Bellini-Giantott04	4.93	2.01	2.57	3.35	1.61	1.95	3.60	2.67	3.00	3.42	2.28	2.25	3.05	2.03	2.33	2.81	3.16	1.86	2.89	2.55	1.78	2.67	3.02	2.26	2.11	2.63	0.00	2.90	3.41	2.57	2.92	2.84	2.94	3.02	1.99	3.71	3.58	2.28	2.31	1.93	2.62	1.83	2.32	3.26	3.20	
Kin-Bowleg4	4.88	2.38	2.75	4.85	3.82	2.73	4.88	4.03	4.07	3.67	2.25	3.70	3.28	3.64	3.43	3.80	3.86	2.77	3.85	3.69	3.44	4.03	4.64	2.89	3.44	3.52	2.90	0.00	3.85	3.65	4.35	4.27	3.78	3.85	3.59	4.79	4.70	3.87	3.76	2.75	3.12	2.86	3.37	4.09	3.58	
Repin-Lugansk04	5.13	3.34	4.04	4.82	3.38	2.34	4.87	3.38	3.59	3.85																																				



Phantasy (Lester structure, complete performances, combined tempo and dynamics)

	PN	Koldofsky-Steuermann51	Varga-Krenek51	Kolisch-Stoek53	Kolisch-Willmann53	Bress-Reiner62	Baker-Gould64	Kolisch-Johansen65	Menahin-Gould65	Goldberg-Webster66	Kolisch-Johansen66	Gross-Grayson74	Gotkovsky-Gotkovsky76	Kremer-Maisenberg77	Kagan-Lobamov78	Uchida-Grosvonts78	Adolf-Litwin94	Kremer-Maisenberg94	Israelievich-Lemelino90	Lang-Lang0	Yaroslav-Meer-Grotenhuis01	Walch-Korber01	Wolyn-Kontinen01	Huang-Vainstein02	Koh-Uchida03	Repin-Lugansky04	Doili-Martono5	Borup-Ernst06	Widmann-Lepper06	Frayanova-Pashchenko08	Colbertson-Appel10	Moller-Oquist10	Reich-Kolodenco10	Sabatke-Oddishier10	Yamada-Kiyochi10	Kozarev-Pudovkin11	Fukuhara-Roden11	David-Gompere12	Soltan-Aviv12	Swenson-Chung12	Degand-Peyrebrune13	Felberg-Gordon13			
PN	0	3.4	3.34	4.97	4.52	4.26	5.16	4.41	4.58	7.04	2.98	5.06	2.56	4.29	3.68	2.8	2.77	2.01	1.52	2.01	2.49	3.46	3.16	2.09	2.96	2.76	3.82	2.79	2.21	2.95	4.22	3.12	5.18	2.9	3.59	3.73	2.59	3.15	1.78	3.14	4.27	2.88	4.56	3.04	3.62
Koldofsky-Steuermann51	3.4	0	4.62	6.04	4.49	5.17	4.91	5.9	5.81	7.49	6.05	5.89	3.81	3.81	4.99	5.08	4.61	4.68	3.86	4.52	6.08	4.59	4.3	5.94	5.06	4.86	5.68	6.04	3.58	4.79	5.1	5.04	6.07	4.41	6.61	3.8	4.95	4.38	4.62	6.23	4.8	6.2	5.38	4.77	
Varga-Krenek51	3.34	4.62	0	5.83	5.49	4.7	5.63	4.76	4.8	6.92	4.16	4.45	3.2	4.77	5.01	3.82	3.39	3.22	4.03	3.14	3.74	4.47	4.42	3.84	3.9	3.91	4.06	3.84	4.72	2.93	4.61	4.53	5.78	3.9	4.38	5.66	3.97	3.46	2.54	3.76	5.91	3.72	4.55	4.98	4.36
Kolisch-Stoek53	4.97	6.04	5.83	0	5.81	6.76	7.95	7.2	6.95	8.5	6.93	8.16	6.06	7.36	5.96	4.73	4.89	5.45	5.12	5.9	4.81	6.55	5.58	5	5.56	6.2	7.22	6.47	7.17	5.31	7.05	6.89	7.04	5.68	6.93	7.57	5.32	5.33	5.97	5.95	6.23	6.39	6.95	6.1	7.6
Kolisch-Willmann53	4.52	4.49	5.49	5.81	0	4.06	6.27	4.96	4.48	6.93	7.4	5.04	6.18	7.37	5.94	5.25	5.75	6.22	4.93	6.15	5.36	5.5	5.83	5.57	6.64	5.8	5.68	6.49	7.19	4.49	5.16	5.27	6.16	6.04	5.91	7.2	4.89	5.23	4.84	6.61	6.03	5.21	6.5	5.83	7.05
Kolisch-Willmann54	4.26	5.17	4.7	6.76	4.06	0	7.04	4.91	4.09	6.51	6.96	3.69	6.04	6.89	5.96	4.22	4.51	5.15	4.31	5.06	5.11	5.5	5.9	5.1	5.7	4.4	5.59	4.73	6.04	4.01	4.43	4.51	6	5.68	5.04	6.21	3.97	5.26	4.42	4.81	6.07	3.75	4.7	5.86	5.43
Bress-Reiner62	5.16	4.91	5.63	7.95	6.27	7.04	0	4.81	7.17	5.58	5.65	7.31	5.38	5.89	6.64	6.48	5.94	5.62	5.53	5.23	6.1	7.07	6.18	4.43	6.66	6.03	5.74	6.98	7.49	4.55	4.73	5.9	6.86	6.63	4.85	6.64	5.31	5.47	6.21	5.97	7.08	4.89	6.96	5.69	5.45
Baker-Gould64	4.41	5.9	4.76	7.2	4.96	4.91	4.81	0	5.78	4.71	5.67	5.61	5.41	5.65	4.46	5.27	4.85	4.21	4.48	4.41	4.36	5.49	4.94	4.66	5.76	5.04	5.2	4.53	5.83	3.79	3.97	4.72	5.87	5.25	3.9	5.72	4.51	4.85	5.25	5.75	5.72	3.49	5.36	4.65	4.45
Kolisch-Johansen65	4.58	5.81	4.8	6.95	4.48	4.09	7.17	5.78	0	8.14	7.67	4.84	4.84	7.76	5.74	4.2	5.97	5.75	4.84	5.57	5.12	6.71	7.53	6.25	6.28	4.99	5.96	5.88	5.82	4.34	6.37	4.81	7.78	5.18	6.63	7.68	4.69	6.19	5.59	6.81	4.71	5.19	6.25	5.42	6.64
Menahin-Gould65	7.04	7.49	6.92	8.5	6.93	6.51	5.58	4.71	8.14	0	7.09	8.17	7.89	7.37	8.22	7.14	6.32	6.75	6.67	6.81	7.25	7.69	6.08	6.58	8.73	7.68	6.76	6.49	8.44	5.74	4.36	6.52	6.02	7.65	5.37	7.81	7.13	6.26	7.09	7.7	7.87	5.62	6.59	7.36	7.27
Goldberg-Webster66	2.98	6.05	4.16	6.93	7.4	6.96	5.65	5.67	7.67	7.09	0	6.04	4.29	5.33	6.18	5.41	4.97	3.25	3.42	3.2	5.28	4.77	5.06	3.86	3.81	4.32	5.82	4.27	3.42	3.87	5.41	4.89	7.45	4.47	3.71	5.34	4.49	3.56	4.12	4.04	7.37	5.16	4.91	6.04	4.82
Kolisch-Johansen66	5.06	5.89	4.45	8.16	5.04	3.69	7.31	5.61	4.84	8.17	6.04	0	5.83	7	5.62	5.05	5.86	5.72	7.94	5.27	5.43	4.74	5.75	5.66	5.48	5.64	6.02	5.7	5.75	5.06	5.3	4.89	7.39	6.38	5.62	7.04	4.49	5.24	4.12	6.35	7.74	5.35	5.57	6.63	5.39
Gross-Grayson74	2.56	3.81	3.2	6.06	6.18	6.04	5.38	5.41	4.84	7.89	4.29	5.83	0	4.9	5.56	4.43	4.55	2.68	3.24	1.85	4.44	4.54	4.83	3.39	4.31	3.79	4.24	3.1	4.2	3.4	5.33	4.88	5.61	3.97	4.18	5.67	4.18	3.64	3.35	2.75	5.09	3.76	6	4.55	3.48
Gotkovsky-Gotkovsky76	4.29	3.81	4.77	7.36	7.37	6.89	5.89	5.65	7.76	7.37	5.33	7	4.9	0	6.57	6.48	5.48	4.76	4.26	3.86	5.6	5.91	3.91	4.94	4.23	5.63	4.5	5.62	5.38	4.12	6.04	5.91	5.97	6.4	3.98	6.66	5.43	4.71	4.72	5.12	6.89	4.96	6.87	5.01	3.83
Kremer-Maisenberg77	3.68	4.99	5.01	5.96	5.94	5.96	6.64	4.46	5.74	8.22	6.18	5.62	5.56	6.57	0	4.01	4.62	4.39	4.2	5.08	3.89	4.63	4.96	4.24	3.69	4.21	4.91	5.51	4.85	5.21	5.36	4.72	7.21	4.21	5.62	5.22	3.93	4.86	4.33	5.01	5.14	4.61	4.33	4.78	5.57
Kagan-Lobamov78	2.8	5.08	3.82	4.73	5.25	4.22	6.48	5.27	4.2	7.14	5.41	5.05	4.43	6.48	4.01	0	2.52	3.98	2.94	4.46	3.44	4.27	4.42	3.63	3.98	3.49	5.43	4	4.62	3.66	4.7	4.23	6.23	4.58	4.89	5.5	3.97	3.59	3.63	4.18	4.72	3.65	3.35	5.21	5.76
Veselka-Oratovova85	2.77	4.61	3.39	4.89	5.75	4.51	5.94	4.85	5.97	6.32	4.97	5.86	4.55	4.48	4.62	2.52	0	2.9	3.29	3.75	3.61	3.51	3.33	2.71	3.44	3.29	4.94	3.8	4.73	3	3.78	4.15	5.52	4.17	3.84	4.38	3.71	3.08	3.16	4.15	5.76	3.86	4.43	4.46	4
Arditti-Litwin94	2.01	4.68	3.22	5.45	6.22	5.15	5.62	4.21	5.75	6.75	3.25	5.72	2.68	4.76	4.39	3.98	2.9	0	3.49	2.47	2.79	4.8	3.33	2.78	2.68	3.26	4.28	2.7	3.08	2.54	4.25	3.96	5.24	3.7	3.06	4.64	3.28	2.87	3.31	2.66	5.41	2.52	4.8	4.4	3.22
Kremer-Maisenberg94	1.52	4.34	4.03	5.12	4.93	4.31	5.53	4.48	4.84	6.67	3.42	4.94	3.24	4.26	4.2	2.94	3.29	3.49	0	2.98	3.31	3.59	3.06	3.09	3.45	4.09	3.76	3.76	3.38	3.82	4.62	3.6	5.35	3.31	3.86	4.21	3.39	3.26	2.66	3.84	4.59	3.33	5.05	3.35	4.58
Israelievich-Lemelino90	2.01	3.86	3.14	5.9	6.15	5.06	5.23	4.41	5.57	6.81	3.2	5.27	1.85	3.86	5.08	4.46	3.75	2.47	2.98	0	3.28	4.6	3.58	3.5	2.94	4.09	4.28	3.14	2.84	2.75	4.21	4.49	4.81	3.75	2.98	5.52	3.06	2.8	3.2	2.63	4.4	3.22	5.37	3.86	3.26
Lang-Lang0	2.49	4.52	3.74	4.81	5.36	5.11	6.1	4.36	5.12	7.25	5.28	5.43	4.44	5.6	3.89	3.44	3.61	2.79	3.31	3.28	0	4.24	3.81	3.36	3.55	3.72	4.4	4.23	4.44	2.96	4.46	4.49	5.02	4.25	4.98	4.75	3.53	4.32	3.12	4.75	5.07	4.27	5.04	4.69	4.81
VanDerMeer-Grotenhuis01	3.46	6.08	4.47	6.55	5.5	5.5	7.07	5.49	6.71	7.69	4.77	4.74	4.54	5.91	4.63	4.27	3.51	4.8	3.59	4.6	4.24	0	4.27	3.4	4.1	3.79	5.68	5.31	4.38	5.11	4.26	4.27	7.51	3.47	4.58	4	4.74	3.99	3.4	4.85	6.53	3.51	5.29	5.55	4.88
Walch-Korber01	3.16	5.49	4.42	5.58	5.83	5.9	6.18	4.94	7.53	6.08	5.06	5.75	4.83	3.91	4.96	4.42	3.33	3.33	3.06	3.58	3.81	4.27	0	3.22	3.66	4.35	5.48	3.8	5.03	4.39	4.56	5.44	5.41	5.7	2.98	5.15	4.64	3.03	3.21	3.52	6.35	4.57	5.1	5.15	4.19
Walsh-Pontinen01	2.09	4.3	3.84	5	5.57	5.1	4.43	4.66	6.25	6.58	3.86	5.66	3.39	4.94	4.24	3.63	2.71	2.78	3.09	3.5	3.36	3.4	3.22	0	2.91	3.35	5.4	4.59	3.82	3.04	4.01	3.79	6.2	3.68	3.33	4.69	3.82	3	2.92	3.32	5.99	3.7	5.09	4.94	3.67
Huang-Vainstein02	2.96	5.94	3.9	5.56	6.64	5.7	6.66	5.76	6.28	8.73	3.81	5.48	4.31	4.23	3.69	3.98	3.44	2.68	3.45	2.94	3.55	4.1	3.66	2.91	0	3.44	4.67	4.46	2.98	3.51	5.33	4.29	6.76	4.4	4.83	3.91	4.08	4.05	2.61	3.98	6.31	4.02	4.75	5.65	3.89
Koh-Uchida03	2.76	5.06	3.91	6.2	5.8	4.4	6.03	5.04	4.99	7.68	4.32	5.64	3.79	5.63	4.21	3.49	3.29	3.26	3.89	4.09	3.72	3.79	4.35	3.35	3.44	0	5.49	3.02	4.52	3.8	4.51	3.44	7.13	4	4.8	4.03	3.58	3.58	3.51	3.42	5.62	3.14	4.88	5.23	4.2
Bellini-Giannotti04	3.82	4.86	4.06	7.22	5.68	5.59	5.74	5.2	5.96	6.76	5.82	6.02	4.24	4.5	4.91	5.43	4.94	4.28	4.76	3.28	4.4	5.68	5.48	5.4	4.67	5.49	0	4.8	5.16	3.7	4.54	4.88	5.86	5.43	4.35	6.24	5.4	4.62	3.83	5.04	5.61	4.61	6.57	4.09	4.66
Kim-Bowles04	2.79	5.68	3.84	6.47	6.49	4.73	6.98	4.53	5.88	6.49	4.27	5.7	3.1	5.62	5.51	4	3.8	2.7	3.76	3.14	4.23	3.31	3.8	4.59	4.46	3.02	4.8	0	3.95	3.69	4.96	4.95	5.23	5.07	3.54	5.12	4.09	4.05	4.37	3.51	5.98	2.75	4.99	4.56	4.02
Repin-Lugansky04	2.21	6.04	4.72	7.17	7.19	6.04	7.49	5.83	5.82	8.44	3.42	5.75	4.2	5.38	4.85	4.62	4.73	3.08	3.38	2.84	4.44	4																							

## Phantasy (Lester structure, Section 0, combined tempo and dynamics)

	PN	Koldosky-Steuermann51	Varga-Krenek51	Kolisch-Stoc43	Kolisch-Willmann53	Kolisch-Willmann54	Bress-Reiner62	Baker-Gould64	Kolisch-Johansen65	Menyhin-Gould65	Goldberg-Webster66	Kolisch-Johansen66	Gross-Grayson74	Gotkovsky-Gotkovsky76	Kremer-Maisenberg77	Kagan-Lobanov78	Veselka-Dratvova85	Arditti-Litwin94	Kremer-Maisenberg94	Israelievitch-Lemelin00	Lang-Lang00	VanderMeer-Grotenhuis01	Walch-Korber01	Wallin-Pontinen01	Huang-Vainstein02	Koh-Uchida03	Bellini-Gianotti04	Kim-Bowles04	Repp-Lugansky04	Dall-Morton05	Borup-Ernst06	Widmann-Lepper06	Frayanova-Pashchenko08	Colbentson-Appel10	Moller-Oquist10	Reich-Kolodent10	Schulte-Oldfather10	Yamada-Kynchio10	Anderegg-Funderburk11	Fukuhara-Roden11	David-Gompfer12	Soltau-Auvil12	Svenson-Chung12	Degand-Peyrebrune13	Felberg-Gordon13		
PN	0	4.19	3.91	5.37	3.4	4.09	6.01	3.81	3.75	5.07	3.87	4.87	3.35	4.41	2.98	2.48	3.69	3.93	3.22	3.27	3.56	4.63	3.55	2.88	3.34	3.79	4.27	4.16	2.71	3.51	3.59	3.64	3.85	2.85	4.7	3.43	3.66	3.55	3.19	3.88	3.84	3.1	5.62	4.5	5.45		
Koldosky-Steuermann51	4.19	0	5.14	7.78	4.34	4.81	5.94	4.65	5.03	5.08	5.17	5.32	4.43	5	5.1	4.68	5.08	5.01	5.02	4.46	4.28	5.99	4.95	4.26	5.11	4.92	4.23	5.44	4.76	3.98	3.35	5.26	5.33	5.26	3.99	5.91	4.75	4.87	4.48	5.12	6.3	4.15	6.47	6.79	5.77		
Varga-Krenek51	3.91	5.14	0	7.83	5.19	5.19	7.16	5.51	4.72	6.14	4.92	5.61	4.8	5.94	4.89	4.31	4.61	5.39	5.53	4.73	5.37	6.4	5.23	4.67	4.94	5.03	5.25	4.7	4.89	4.07	4.48	4.63	5.47	4.43	5.09	5.39	5.25	3.85	4.86	5.37	6.03	4.89	6.38	6.49	6.29		
Kolisch-Stoc43	5.37	7.78	7.83	0	6.43	7.43	8.29	7.02	7.46	8.35	7.77	7.72	7.18	7.21	7.31	6.86	7.67	7.28	6.68	7.52	7.12	7.36	7.27	6.99	7.36	7.02	8.23	7.17	6.51	7.15	7.14	7.61	8.02	6.5	8.46	6.9	6.79	7.41	7.32	7.98	6.44	7.14	7.59	7.53			
Kolisch-Willmann53	3.4	4.34	5.19	6.43	0	3.89	6.73	3.92	3.44	5.39	4.77	4.09	3.73	5.88	5.01	3.98	4.77	5	4.89	4.47	4.9	5.5	4.58	4.51	5.2	4.77	5.48	4.75	4.15	4.63	4.31	5.29	5.44	3.57	4.86	5.29	4.51	5.12	4.63	5.39	5.43	4.12	6.45	5.93	6.11		
Kolisch-Willmann54	4.09	4.81	5.19	7.43	3.89	0	6.46	5.2	4.28	5.9	5.44	4.29	4.16	5.94	5.32	3.95	5.12	6	5.19	4.86	5.43	5.9	5.46	4.86	5.64	4.93	5.29	5.05	4.82	4.58	4.1	4.94	5.91	5.04	5.49	4.9	5.71	5.35	4.93	5.66	6.1	4.31	6.74	6.9	6.05		
Bress-Reiner62	6.01	5.94	7.16	8.29	6.73	4.46	0	6.19	5.98	7.01	7.16	7.02	6.15	6.93	6.83	7.04	7.05	6.7	6.51	6.73	7.2	6.71	6.82	6.79	7.19	6.34	6.05	6.5	6.74	6.17	6.07	6.33	7.16	6.54	5.86	7.27	6.48	7.04	6.75	6.01	7.09	5.6	6.11	6.75	6.72		
Baker-Gould64	3.81	4.65	5.51	7.02	3.92	5.2	6.19	0	4.71	5.93	5.91	5.6	4.2	6.11	4.58	5.14	5.01	5.35	5.08	4.12	5.48	5.76	5.19	4.74	5.04	4.52	5.68	4.33	4.84	5.19	5.07	5.32	6.13	3.58	5.72	5.86	5.29	5.51	5.2	5.19	5.87	4.15	6.41	6.39	5.7		
Kolisch-Johansen65	3.75	5.03	4.72	7.46	3.44	4.28	5.98	4.71	0	6.12	5.45	4.36	4.62	4.44	4.79	4.22	5.4	5.91	5.26	4.83	5.08	5.34	5.36	4.77	5.12	5.36	5.44	5.08	4.45	4.39	4.47	4.57	6.22	4.61	5.06	5.31	5.19	5.37	4.5	5.68	5.93	5.06	5.95	6.26	5.8		
Menyhin-Gould65	5.07	5.08	6.14	8.35	5.39	5.9	7.01	5.93	6.12	0	5.05	7.1	6.55	0	4.81	5.91	5.62	5.58	5.19	6.65	5.72	4.71	5.46	6.01	5.18	5.27	5.5	5.57	6.32	5.19	5.34	4.94	4.79	5.52	5.89	5.85	5.93	6	5.51	5.39	5.15	6.24	7.13	4.97	7.18	7.22	5.99
Goldberg-Webster66	3.87	5.17	4.92	7.77	4.77	5.44	7.16	5.91	5.45	5.05	0	6.55	4.98	6.06	5.61	4.4	4.64	5.47	4.34	4.59	4.58	5.87	5.74	4.31	5.3	4.9	4.91	5.08	4.71	4.81	4.95	5.48	5.29	4.78	5.06	4.77	4.89	4.96	5	5.47	5.69	5.2	6.19	5.72	6.31		
Kolisch-Johansen66	4.87	5.32	5.61	7.72	4.09	4.29	7.02	5.6	4.36	7.1	6.55	0	4.81	5.91	5.62	5.58	5.19	6.65	5.72	4.71	5.46	6.01	5.18	5.27	5.5	5.57	6.32	5.19	5.34	4.94	4.79	5.52	5.89	5.85	5.93	6	5.51	5.39	5.15	6.24	7.13	4.97	7.18	7.22	5.99		
Gross-Grayson74	3.35	4.43	4.8	7.18	3.73	4.16	6.15	4.2	4.62	5.9	4.98	4.81	0	5.21	4.24	4.33	3.65	4.69	4.73	2.46	4.66	5.32	4.34	4.02	4.36	4.26	4.43	4.88	4.09	3.8	3.94	4.27	4.7	3.43	4.48	4.74	3.98	4.8	3.9	4.71	4.92	4.41	6.58	5.24	5.21		
Gotkovsky-Gotkovsky76	4.41	5	5.94	7.21	5.88	5.94	6.93	6.11	6.44	6.91	6.06	5.91	5.21	0	6.23	5.57	5.8	5.44	5.69	5.37	5.21	6.49	5.3	5.06	5.53	5.53	5.34	6.18	5.39	5.32	5.47	5.41	6.29	5.67	6.26	6.23	5.42	5.77	5.58	5.52	5.76	5.5	7.04	6.6	6.98		
Kremer-Maisenberg77	2.98	5.1	4.89	7.31	5.01	5.32	6.83	4.58	4.79	6.12	5.61	5.62	4.24	6.23	0	3.14	4.33	4.51	4.79	3.98	3.91	5.64	4.34	4.1	3.51	4.03	4.87	4.6	3.57	4.12	4.03	4.21	4.01	3.91	5.47	4.28	5.29	3.9	3.83	4.49	5.55	4.13	6.11	5.87	6.43		
Kagan-Lobanov78	2.48	4.68	4.31	6.86	3.98	3.95	7.04	5.14	4.22	5.61	4.4	5.58	4.33	5.57	3.14	0	4.06	4.36	3.56	4.23	3.82	5.26	4.64	3.27	3.24	4.08	4.45	4.65	2.73	3.62	3.65	4.8	4.73	3.73	5.27	3.56	4.3	4.19	3.07	3.8	4.82	4.32	5.39	5.57	5.98		
Veselka-Dratvova85	3.69	5.08	4.61	7.67	4.77	5.12	7.05	5.01	5.4	5.9	4.64	5.19	3.65	5.8	4.33	4.06	0	4.96	4.43	3.12	5.02	5.74	3.66	4.84	3.95	3.94	5.4	5.08	4.16	4.43	4.25	4.61	4.74	4.42	5.34	4.45	4.93	4.06	4.21	4.48	4.81	4.98	6.31	5.48	5.68		
Arditti-Litwin94	3.93	5.01	5.39	7.28	5	6	6.7	5.35	5.91	6.64	5.47	6.65	4.69	5.44	4.51	4.36	4.96	0	4.5	4.28	4.57	6.1	3.89	4.43	4.24	5.11	4.73	5.03	4.2	4.62	4.89	4.9	4.83	4.73	4.81	4.81	4.25	4.61	4.64	4.06	5.46	5.09	5.81	5.3	5.77		
Kremer-Maisenberg94	3.22	5.02	5.53	6.68	4.89	5.19	6.51	5.08	5.26	6.13	4.34	5.72	4.73	5.69	4.79	3.56	4.43	4.5	0	4.35	4.05	5.3	4.8	3.36	3.77	4.68	5.04	3.34	3.76	4.12	4.79	5.4	5.05	4.31	5.35	3.98	4.62	4.94	4.26	4.52	4.61	4.51	6.07	4.88	5.19		
Israelievitch-Lemelin00	3.27	4.46	4.73	7.52	3.47	4.86	6.73	4.12	4.83	5.59	4.59	4.71	2.46	5.37	3.98	4.23	3.12	4.28	4.35	0	4.16	5.5	3.65	3.86	4.12	4.67	4.94	4.68	4.1	4.22	3.96	4.26	4.03	3.52	4.66	5.02	3.94	5.02	4.28	4.74	5.05	4.13	6.89	5.3	5.57		
Lang-Lang00	3.56	4.28	5.37	7.12	4.9	5.43	7.2	5.48	5.08	6.24	4.58	4.66	5.21	3.91	3.82	5.02	4.57	4.05	4.16	0	5.57	5.08	3.76	3.83	4.72	4.17	4.72	4.03	3.56	3.3	5.06	4.77	4.98	5.24	4.63	5	5.16	4.32	4.86	4.93	4.61	6.69	5.97	6.59			
VanderMeer-Grotenhuis01	4.63	5.99	6.4	7.36	5.5	5.9	6.71	5.76	5.34	7.48	5.87	6.01	5.32	6.49	5.64	5.26	5.74	6.1	5.3	5.5	5.57	0	5.2	4.72	5.71	4.75	5.88	4.97	5.56	5.6	5.28	6.42	6.43	5.35	5.67	5.31	5.41	5.85	5.43	4.73	6.08	5.15	6.18	5.9	6		
Walch-Korber01	3.55	4.95	5.23	7.27	4.58	5.46	6.82	5.19	5.36	6.48	5.74	5.18	4.34	5.3	4.34	4.64	3.66	3.89	4.8	3.65	5.08	5.2	0	4.88	4.23	4.26	5.29	4.69	4.38	4.87	4.61	4.61	4.51	4.67	5.09	5.09	4.77	4.28	4.27	4.2	5.35	4.63	5.96	5.37	5.78		
Wallin-Pontinen01	2.88	4.26	4.67	6.99	4.51	4.86	6.79	4.74	4.77	5.96	4.31	5.27	4.02	5.06	4.1	3.27	4.84	4.43	3.36	3.86	3.76	4.72	4.88	0	4.18	3.85	4.26	4.2	3.49	3.36	3.76	4.88	5.12	4.26	5.18	4.82	3.87	4.56	4.23	4.17	5.41	3.67	6.1	5.2	4.93		
Huang-Vainstein02	3.34	5.11	4.94	7.36	5.2	5.64	7.19	5.04	5.12	6.88	5.3	5.5	4.36	5.53	3.51	3.24	3.95	4.24	3.77	4.12	3.83	5.71	4.23	4.18	0	4.48	4.8	5.14	3.63	3.81	4.54	4.22	4.9	4.4	5.75	4.17	5.29	3.63	3.36	6.18	6.1	4.4					
Koh-Uchida03	3.79	4.92	5.03	7.02	4.77	4.93	6.34	4.52	4.36	6	4.9	5.57	4.26	5.53	4.03	4.08	3.94	5.11	4.68	4.67	4.72	4.75	4.26	3.85	4.48	0	4.65	3.96	4.35	4.28	4.54	4.66	5.67	4.52	5.55	4.58	5.05	4.78	4.16	4.09	5.07	3.95	5.49	5.52	5.22		
Bellini-Gianotti04	4.27	4.23	5.25	8.23	5.48	5.29	6.05	5.68	5.44	6	4.91	6.32	4.43	5.34	4.87	4.45	5.4	5.73	5.04	4.94	4.17	5.88	5.29	4.26	4.8	4.65	0	5.34	4.48	3.81	4.32	5.11	5.77	5.01	4.71	5.07	5.61	5.04	4.22	4.03	5.34	4.44	6.59	5.48	5.48		
Kim-Bowles04	4.16	5.44	4.7	7.17	4.75	5.05	6.5	4.33	5.08	5.41	5.08	5.19	4.88	6.18	4.6	4.65	5.08	5.03	4.34	4.68	4.72	4.97	4.69	4.2	5.14	3.96	5.34	0	5.03	4.59	4.17	5.42	5.55	3.93	4.88	5.27	4.65	4.84	5.01	4.11	5.63	4.1	5.84	5.41	5.58		
Repp-Lugansky04	2.71	4.76	4.89	6.51	4.15	4.82	6.74	4.84	4.45	6.04	4.71	5.34	4.09	5.39	3.57	2.73	4.16	4.2	3.76	4.1	4.03	5.56	4.38	3.49	3.63	4.35	4.48	5.																			

## Appendix B. Software listings

### PNT\_Calculator.xlsx

The initial worksheet of this spreadsheet (“params”) allows for certain fixed parameters to be specified in the future. The next worksheet is “PT Calcs” which performs all the appropriate calculations to generate the Performance Norm. The data for each recording is stored on a separate worksheet named in the style violinist-pianistYY (where YY is the recording year). See Discography for details of each recording. The first 5 columns are concerned with calculating average tempo and acceleration rates on a per beat basis. The onset of beats in seconds from commencement of the performance is shown on the leftmost column. The first row is ignored in calculations since neither an initial tempo nor acceleration are meaningful at

PN Worksheet (Sample)

	Ave sec.	Bar/Beat	BPM ave.	BPS ave.	BPS/S ave.	Intermediate calculations for dB ave.					Ave dB SPL	dB Data	Ave dB/10	Antilog	Differences	LOG10	*10	beat
1	4.39	1.2	0.00	0.00	0.00	750205202.66	17050118.24	7.23	72.32	0.00	7.23	17050118.24						
2	5.71	1.3	45.72	0.76	0.34	1460728863.57	33198383.26	7.52	75.21	0.71	7.52	33198383.26			8506390.55	6.93	69.30	27.92
3	6.88	1.4	51.28	0.85	-0.01	1124486386.91	25556508.79	7.41	74.08	-0.95	7.41	25556508.79			-14118772.68	-7.15	-71.50	-28.17
4	8.24	2.1	43.85	0.73	-0.03	839502865.45	19079610.58	7.28	72.81	1.69	7.28	19079610.58			46570711.73	7.67	76.68	28.81
5	9.54	2.2	46.40	0.77	0.05	3173597703.24	72127220.53	7.86	78.58	3.35	7.86	72127220.53			108741474.90	8.04	80.36	32.62
6	10.71	2.3	51.27	0.85	-0.02	5624127760.84	127821085.47	8.11	81.07	-1.02	8.11	127821085.47			-32511723.85	-7.51	-75.12	-29.48
7	12.09	2.4	43.53	0.73	-0.03	1743081853.82	39615496.68	7.60	75.98	-0.18	7.60	39615496.68			-13171230.88	-7.12	-71.20	-26.87
8	13.36	3.1	47.20	0.79	0.07	5044593602.02	114649854.59	8.06	80.59	-0.12	8.06	114649854.59			-2635002.75	-6.42	-64.21	-26.74
9	14.49	3.2	53.11	0.89	-0.01	1627141732.66	36980493.92	7.57	75.68	-2.14	7.57	36980493.92			-80104400.90	-7.90	-79.04	-32.50
10	15.79	3.3	46.07	0.77	-0.02	151999962.60	34545453.70	7.54	75.38	-2.64	7.54	34545453.70			-28839641.92	-7.46	-74.60	-30.00
11	16.97	3.4	50.65	0.84	0.18	358197488.17	8140852.00	6.91	69.11	1.43	6.91	8140852.00			33523811.82	7.53	75.25	36.53
12	17.85	4.1	68.54	1.14	-0.10	2995047682.69	68069265.52	7.83	78.33	-0.92	7.83	68069265.52			-3398537.19	-6.53	-65.31	-25.51
13	19.53	4.2	35.60	0.59	-0.11	208661851.96	4742314.82	6.68	66.76	-6.03	6.68	4742314.82			-66840067.63	-7.83	-78.25	-27.05
14	20.74	4.3	49.68	0.83	0.09	54084707.07	1229197.89	6.09	60.90	0.69	6.09	1229197.89			2254286.79	6.35	63.53	25.88
15	21.99	4.4	48.12	0.80	-0.02	307850470.77	6996601.61	6.84	68.45	2.89	6.84	6996601.61			5322778.10	6.73	67.26	26.75
16	23.26	5.1	47.32	0.79	-0.01	288286943.47	6551975.99	6.82	68.16	-1.66	6.82	6551975.99			-4369297.99	-6.64	-66.40	-25.84
17	24.56	5.2	46.08	0.77	-0.03	115601359.27	2627303.62	6.42	64.20	0.03	6.42	2627303.62			139831.58	5.15	51.46	18.83
18	25.99	5.3	41.93	0.70	-0.03	294439532.88	6691807.57	6.83	68.26	1.38	6.83	6691807.57			3914699.68	6.59	65.93	22.96
19	27.43	5.4	41.65	0.69	0.09	287848145.35	6542003.30	6.82	68.16	0.76	6.82	6542003.30			3729161.91	6.57	65.72	26.01
20	28.52	6.1	55.25	0.92	-0.04	458522657.05	10420969.48	7.02	70.18	-0.70	7.02	10420969.48			-2390569.26	-6.38	-63.79	-22.47
21	30.27	6.2	34.24	0.57	-0.12	182663097.73	4151434.04	6.62	66.18	-1.97	6.62	4151434.04			-8650653.84	-6.94	-69.37	-17.73
22	32.43	6.3	27.78	0.46	-0.01	77893887.99	1770315.64	6.25	62.48	-1.98	6.25	1770315.64			-3487154.39	-6.54	-65.42	-16.26
23	34.29	6.4	32.19	0.54	0.06	29228304.40	664279.65	5.82	58.22	-1.74	5.82	664279.65			-1315152.13	-6.12	-61.19	-18.08
24	35.81	7.1	39.45	0.66	0.04	20027194.09	455163.50	5.66	56.58	4.81	5.66	455163.50			18410306.39	7.27	72.65	23.96
25	37.32	7.2	39.70	0.66	0.01	839281785.52	19074586.03	7.28	72.80	5.45	7.28	19074586.03			18134901.32	7.26	72.59	24.53
26	38.77	7.3	41.46	0.69	0.07	817962852.22	18590064.82	7.27	72.69	-3.38	7.27	18590064.82			-16646691.56	-7.22	-72.21	-27.30
27	39.97	8.1	50.08	0.83	0.01	106827356.80	2427894.47	6.39	63.85	-2.73	6.39	2427894.47			-14976023.41	-7.18	-71.75	-27.53

# Sample worksheet for Koldofsky-Steuermann 1951 recording (extract)

1	Sec	Bar/Beat	BPM	BPS	bpss	dB	dbdt	c	differences	LOG10	x10	dbdt
2	6.50	1.20	45.71	0.00	0.00	71.30	0.00	13489628.83				
3	7.85	1.30	44.18	1.36	0.49	73.00	-1.71	19952623.15	-8812277.413	-6.94508816	-69.4508816	-25.87684926
4	9.18	1.40	45.26	1.33	0.03	66.70	-1.74	4677351.413	-13345688.67	-7.125340989	-71.25340989	-25.82557655
5	10.61	2.10	41.86	1.43	0.06	68.20	2.82	6606934.48	26945425.19	7.430485041	74.30485041	25.26576894
6	12.12	2.20	39.80	1.51	-0.05	75.00	3.14	31622776.6	43511788.88	7.638606939	76.38606939	27.22429738
7	13.42	2.30	46.22	1.30	0.00	77.00	0.71	50118723.36	18495946.76	7.267076567	72.67076567	25.77827371
8	14.94	2.40	39.45	1.52	0.06	77.00	0.07	50118723.36	2362022.662	6.37328406	63.7328406	21.15107478
9	16.43	3.10	40.21	1.49	-0.15	77.20	0.08	52480746.02	2362022.662	6.37328406	63.7328406	24.25916441
10	17.57	3.20	52.87	1.13	-0.09	77.20	-1.32	52480746.02	-27361881.71	-7.437145961	-74.37145961	-30.7383446
11	18.85	3.30	46.70	1.28	-0.02	74.00	-6.69	25118864.32	-51131783.14	-7.708690938	-77.08690938	-32.45377282
12	19.94	3.40	55.01	1.09	-0.26	61.30	1.80	1348962.883	29835223.07	7.474729289	74.74729289	39.68070609
13	20.74	4.10	75.65	0.79	0.28	77.40	-2.47	54954087.39	-1046967.711	-6.019933288	-60.19933288	-22.87350583
14	22.57	4.20	32.63	1.84	0.17	54.80	-7.16	301995.172	-54652092.21	-7.737606792	-77.37606792	-24.50227335
15	23.89	4.30	45.48	1.32	-0.23	64.80	5.39	301995.172	6942364.429	6.841507408	68.41507408	26.72463831
16	25.13	4.40	48.36	1.24	0.01	68.60	5.03	7244359.601	5723600.689	6.757669327	67.57669327	26.16400216
17	26.48	5.10	44.71	1.34	0.03	67.80	-4.68	6025595.861	-6836979.323	-6.834864266	-68.34864266	-25.57224666
18	27.81	5.20	45.09	1.33	0.08	56.10	0.24	407380.2778	1053861.983	6.022783738	60.22783738	20.78902669
19	29.37	5.30	38.31	1.57	0.01	68.50	2.84	7079457.844	2346848.426	6.370485041	63.70485041	21.80267668
20	30.73	5.40	44.26	1.36	-0.18	64.40	-4.35	2754228.703	-6490614.188	-6.812285795	-68.12285795	-27.43878814
21	31.86	6.10	53.23	1.13	0.11	57.70	-2.23	588843.6554	-2093535.255	-6.320880279	-63.20880279	-22.75665515
22	33.51	6.20	36.35	1.65	0.24	58.20	0.27	660693.448	152466.5859	5.183174676	51.83174676	14.12929008
23	35.52	6.30	29.73	2.02	0.12	58.70	-0.34	741310.2413	-182063.3557	-5.260222543	-52.60222543	-12.68459176
24	37.65	6.40	28.18	2.13	-0.17	56.80	-4.82	478630.0923	-726855.8436	-5.861448286	-58.61448286	-16.52410437
25	39.07	7.10	42.31	1.42	-0.22	41.60	5.26	14454.39771	15739470.88	7.196990128	71.96990128	24.7649239
26	40.56	7.20	40.33	1.49	0.06	72.10	10.49	16218100.97	25104409.92	7.399750018	73.99750018	23.96376569
27	42.16	7.30	37.50	1.60	-0.10	74.00	-3.26	25118864.32	-14268256.37	-7.154370904	-71.54370904	-25.37541475
28	43.38	8.10	49.20	1.22	0.01	62.90	-5.38	1949844.6	-24394428.36	-7.387290646	-73.87290646	-25.82600183

params	PT Cates	Koldofsky-Steuermann51	David-Gompper12	Varga-Krenek61	Koltach-Stock53	Koltisch-Willmann53	Koltisch-Willmann53
--------	----------	------------------------	-----------------	----------------	-----------------	---------------------	---------------------

## SAXIFY.R

```
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#####
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# (3) commercial use is not permitted of this code or any derived works;
# (4) the code for purposes of this license is deemed to include and cover: Saxify.R file
# and related files Work.R, Section.R and Plotter.R
#####
```

```
# Phase 0: Purpose:
#####
# Saxify.R is the main control program for the Saxify analytic model of music
performances.
# It assumes the data is presented in an Excel worksheet (one performance per tab).
# Note recommendations to replace Excel worksheets with a database in future releases
# All code is written in R:
# R Core Team (2013). R: A language and environment for statistical computing.
# R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.
# The program uses two R6 classes (Work.R and Section.R both listed herein) to
# handle calculations. Work.R defines all the performances of a Work. Section.R is
# instantiated from the structural Performance Map which specifies how each
performance
# is segmented – this may be defined over very high-level structures such as A, B, B'
etc,
# or it may be defined over lower level bar groups, or even individual bars.

# NOTE: Items tagged FR01, FR02 etc are suggestions for Future Releases of this
software
#####
```

```
# Phase 1: Load the required R Libraries
#####
# Clustering functions library
# (GPL-2 license @ https://cran.r-project.org/web/licenses/GPL-2)
# Pablo Montero, José A. Vilar (2014). TSclust: An R Package for Time Series
Clustering.
# Journal of Statistical Software, 62(1), 1-43. URL http://www.jstatsoft.org/v62/i01/.
#####
```

```
library(TSclust)
```

```
#####  
# Functions to read/write Excel worksheets  
# (GPL-3 license @ https://cran.r-project.org/web/licenses/GPL-3)  
# Hadley Wickham and Jennifer Bryan (2018). readxl: Read Excel Files. R package  
# version 1.1.0. https://CRAN.R-project.org/package=readxl  
#####
```

```
library(readxl)
```

```
#####  
# Standard class library for R6 type  
# (MIT+file license @ https://cran.r-project.org/web/licenses/MIT)  
# Winston Chang (2017). R6: Classes with Reference Semantics. R package version  
2.2.2.  
# https://CRAN.R-project.org/package=R6  
#####
```

```
library(R6)
```

```
#####  
# Excel manipulation library  
# (GPL-3 license @ https://cran.r-project.org/web/licenses/GPL-3)  
# Adrian A. Dragulescu (2014). xlsx: Read, write, format Excel 2007 and  
# Excel 97/2000/XP/2003 files.  
# R package version 0.5.7. https://CRAN.R-project.org/package=xlsx  
#####
```

```
library(xlsx)
```

```
#####  
# Phase 2: Initialisation  
#####  
ptm <- proc.time() # Start the clock!  
cat("\014")        # Clear the console  
print ("Starting") # Print start-time on the console
```

```
#####  
# Include Class definitions from wherever the Section.R and Work.R files are located.  
# You need fully specified paths (the ones shown are for Mac OSX 13.10 so adjust for  
# your Operating System). You may choose to place the files on Dropbox, in which case  
# the following examples will work. In general, when reading this code, replace  
<folder>  
# with any suitable folder or directory that you have created for your specific operating  
system.  
#####
```

```
locationSection <- "/Users/<user>/Dropbox/<folder>/Section.R"  
locationWork <- "/Users/<user>/Dropbox/<folder>/Work.R"
```

```
source(locationWork)
source(locationSection)
```

```
#####
# Set parameters for a run
#####
# Saxify assumes a 1-based column index in PNTCalculator.xlsx
# PNT... defines columns in PNT sheet (Performance Norm Tensor)
# REC... defines columns in standard performance recording data

# Here is the base folder path (on Mac OSX 10.13.x) which is assumed
# (but not necessarily) to be on Dropbox. It may need adjustment for Windows or
# Linux. All input data for the run will be read from the base folder location. Further
# initialization writes outputs to specific, named sub-folders (or subsub0folders) of the
# base folder (which must exist, and have write/edit permissions)
#####

genLoc <- path.expand("~/Dropbox/<folder>/<subfolder>/<subsubfolder> /")

#####
# _OUTPUT/ is sub-folder for rates of change DMs and controls the columns
# selected; _OUTPUT1/ is sub-folder for absolute values. Folder names may be
# extended for other types of data
# FR01: consider using a character array Output[ of folder names to provide greater
flexibility
# This defines where output data will be written by a run of Saxify
#####

folderForOutput <- "_OUTPUT1/"

#####
# FINAL Outputs need column headings as see below. These may be
customized/localized
# as necessary. Note that all column indices are 1-based
#####

if (folderForOutput == "_OUTPUT/") {
  # Rates of change (_OUTPUT/)
  PNTcol1 <- 5
  PNTcolHead1 <- "Bpss"
  PNTcol2 <- 10
  PNTcolHead2 <- "dbDelta"
  RECcol1 <- 5
  RECcolHead1 <- "Bpss"
  RECcol2 <- 7
  RECcolHead2 <- "dbDelta"
}

if (folderForOutput == "_OUTPUT1/") {
#####
# absolute values (_OUTPUT1/)
```

```
#####

PNTcol1 <- 4
PNTcolHead1 <- "BPM"
PNTcol2 <- 9
PNTcolHead2 <- "dB"
RECcol1 <- 4
RECcolHead1 <- "BPM"
RECcol2 <- 6
RECcolHead2 <- "dB"
}

#####
# Equal-sized frames are used – this is a parameter of the PAA Phase. Ideally frames
# should be an integer dividend of the seriesLength
#####

frames <- 100

#####
# size of the symbol alphabet: It is recommended to set this in range 5-8
#####

alpha <- 8

#####
# names of performance variables
#####

varNames <- c("Bpss", "dbDelta")

#####
# number of independent performance variables
#####

vars <- length(varNames)

#####
# weights are specified to 2 decimal places, must sum to 1, and have as
# many values as vars #(above)
#####

weights <- c(0.50,0.50)

#####
# this allows the processing to ignore either lead-in or lead-out or both
#####

beatsDroppedStart <- 0
beatsDroppedEnd <- 0
```



```
#####
# location of input data – stored as one performance per tab, plus the PN
# average performance
# FR02: consider using a database – certainly for inputs and possibly for outputs
#####

locationPNT<- paste(genLoc, "_PNT_Calculator.xlsx", sep="")

#####
# A known bug in write.xlsx requires path.expand to specify full path to output. The
# workbook named dmFull.xls is the DM for all variables combined
#####

locationDM <- path.expand(paste(genLoc, paste(folderForOutput, "dmFull.xlsx",
sep=""), sep=""))
locDM <- path.expand(paste(genLoc, folderForOutput, sep=""))

#####
# store the location of the _recordings.csv file which is used to access the tabs on the
# input data sheet
#####

locationRECORDINGS<- path.expand(paste(genLoc, "_recordings.csv", sep=""))

#####
# Store the location of the _map.csv file which is used to segment
# a recording. Important fields are as follows
# (others should be completed but are not used for current processing
# FR03: redesign the Map as a database object
#####

locationMAP <-path.expand(paste(genLoc, "_map.csv", sep=""))

#####
# Name the sheets in the Excel workbook that hold performance data (excluding PN).
# To add a new performance:
# (1) make an entry in the record_tabs vector (the csv file) and add the performance data
to a ## new Excel tab in the input worksheet with the exact same name as in the CSV
file

record_tabs = read.csv(file=locationRECORDINGS, header = FALSE, sep = "")
record_tabs <- as.matrix(record_tabs)

#####
# FR04: redesign _recordings.csv as a database object
# Declare a new Work and all its Section objects. This creates a new Work object
# from the Work.R class template and automatically initializes all its own Sections
# from the Work object constructor
#####
```

```
w <- Work$new(record_tabs, varNames, alpha, frames, weights, beatsDroppedStart,
beatsDroppedEnd, locationDM)
```

```
#####
# Phase 3: Perform the Run
```

```
# All code above this point has been concerned with setting parameters and file
locations.
```

```
#####
```

```
#####
```

```
# >>> Phase 3a: Commence the actual run by printing initialization data
```

```
#####
```

```
cat (w$name)
cat ("\n\nPerformance Analytics\n")
cat (date())
cat ("\n-----\n\n")
cat ("Process performances data from Excel - (")
cat (length(record_tabs))
cat(" performances) ...\n\n")
cat ("PNT, ")
```

```
#####
```

```
# >>> Phase 3b: Get the PN and all performances, to generate symbolic
# representations. The Work object's getData() function
# is used to perform all reads. Create the PAA, for each
# performance, then the symbolic approximations, and
# finally store in arrays for later use
```

```
#####
```

```
w$getData()
```

```
#####
```

```
# >>> Phase 3c: Process the data from Phase 3b to create dissimilarity
# matrices in a loop. Calculate the DM by doing pairwise
# comparisons of each symbolic string. Type : 1=combined,
# 2=first variable, 3 = second variable etc
```

```
#####
```

```
cat("\n\n")
```

```
#####
```

```
# FR07: consider calculating type as a parameter from other values rather than
# specifying as fixed value 3 on this next loop
```

```
#####
```

```
for (type in 3:1) {
  cat ("\n")
  cat ("Calculating performance dissimilarity matrix...")
  cat (type)
```

```

cat ("/")
cat (vars+1)
cat ("\n")
w$doDistanceMatrix(type)
}

#####
# >>> Phase 3d:          repeat all processing for each section of the performance
#                        and create individual DMs
#                        (by parameter and for all parameters combined).
#
# FR06: Consider doing the section calculations per performance immediately after the
# complete work is processed by moving the call to w$doSectionDMS() from
# Saxify.R to Work.R. Evaluate any necessary re-coding in Work.R
#####

w$doSectionDMS().

#####
# Finally... exit
#####

cat ("\n...Run ended\n\n")
# Stop the clock
print (proc.time() - ptm)

```

## WORK.R

```
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# (3) commercial use is not permitted of this code or any derived works;
# (4) the code for purposes of this license is deemed to include and cover: Saxify.R file
# and related files Work.R, Section.R and Plotter.R
#####

#####
# Phase 0: Purpose:
#####
# This file defines a R6 class named 'Work' to represent the complete corpus of
# recordings of a musical work being processed in a run of Saxify.
# A Work object will be created by the calling program to
# represent all of the performances. For each performance this class
# will then generate one Section object for each structural segment mapped in the
# work.
#####

#####
# Individual DMs (dmX, dmY, dmZ etc) need to be declared, and initialized for
# each performance variable. Size of each DM will be the length of the performances
# vector.
# FR08: This may be improved in a revised version of this code - use an object array of
# DM
#####

#####
# defines the public/private data of the Class and the methods used by it
#####
Work <- R6Class("Work",
  public = list(
    name = "character",
    sections = list(),
    SAXarray = list(),
    SAXarrayx = list(),
    SAXarrayy = list(),
    dm = matrix(),
```

```

dmx = matrix(),
dmy = matrix(),
performances = c(),
xls = array(),
x = c(),
y = c(),
z = c(),
seriesLength = "numeric",
paa = c(),
paax = c(),
paay = c(),
SAXstring = "character",
SAXstringx = "character",
SAXstringy = "character",
alpha = "numeric",
frames = "numeric",
varNames = c(),
weights = c(),
beatsDroppedStart = "numeric",
beatsDroppedEnd = "numeric",
locationDM = "character",
myMap = matrix(),

#####
# Initialize is the class constructor, called immediately and automatically when an object
# of this class is created. The calling program Saxify.R passes the parameters that are
# shown in parentheses
#####
initialize = function(performances, varNames, alpha, frames, weights,
beatsDroppedStart, beatsDroppedEnd, locationDM) {
  self$name <- "Schoenberg Phantasy Op. 47"
  self$performances <- c(performances)
  self$SAXarray <- list(length(performances)+1)
  self$SAXarrayx <- list(length(performances)+1)
  self$SAXarrayy <- list(length(performances)+1)
  self$varNames <- varNames
  self$alpha <- alpha
  self$frames <- frames
  self$weights <- weights
  self$beatsDroppedStart <- beatsDroppedStart
  self$beatsDroppedEnd <- beatsDroppedEnd
  self$locationDM <- locationDM

#####
# map is generated from a textfile named map.csv to represent the section
# segmentation of the work. Each item in the map is used to create a Section
# object stored as a new Section object in the myMap array
#####

myMap = read.csv(file=locationMAP, header = TRUE, sep = ",")
myMap <- as.matrix(myMap)

```

```

    for(i in 1:dim(myMap)[1]) { # for each row

self$addSections(Section$new(as.numeric(myMap[i,1]),myMap[i,2],as.numeric(myMap[
i,3),

as.numeric(myMap[i,4]),as.numeric(myMap[i,5]),as.numeric(myMap[i,6]),myMap[i,7],as.
numeric(myMap[i,8]),myMap[i,9],as.numeric(myMap[i,10]),
        as.numeric(myMap[i, 11]), as.numeric(myMap[i,12])))
    }

#####
# Initialize the DM for the complete work then create a DM; add 1 extra column
# to cover the PNT
#####

self$dm = matrix(nrow=length(self$performances)+1,
ncol=length(self$performances)+1)

#####
# create individual DMs for each of the individual variables. These will output to new
# tabs on # the worksheet
#####

    self$dmx = matrix(nrow=length(self$performances)+1,
ncol=length(self$performances)+1)
    self$dmy = matrix(nrow=length(self$performances)+1,
ncol=length(self$performances)+1)
    },

    addSections = function(s) {
        self$sections <- c(self$sections, s)
    },

#####
# This function calculates pairwise SAX distances using the MINDIST calculation
# for a pair of strings but may use any string comparison (eg Levenshtein Distance)
# so long as it returns a dissimilarity or distance as a numeric. Dissimilarities are
# rounded to 2 decimal points
#####

    pairwise = function (strA, strB) {
        v <- mindist.sax(strA, strB, self$alpha, self$seriesLength)
        return (as.numeric(format(round(v,2), nsmall=2)))
    },

#####
# This function reads the input data – firstly the PN and then each performance. It
# normalizes each series by subtracting its arithmetic mean and dividing by its

```

```

# standard deviation. Optionally it calculates a weighted combination, performs
# Piecewise Aggregate Approximation - symbolizes each PAA string and stores.
# The doDistanceMatrix function will be eventually called by the calling program
# Saxify.R to generate DMs that include all performances across the variable types.
#####

getData = function() {

  self$xls <- read_xlsx(locationPNT, col_types=NULL, sheet="PT Calcs",
col_names=TRUE, skip=1)

  self$x = as.numeric( self$xls[[PNTcol1 ]
self$y = as.numeric( self$xls[[PNTcol2 ]

#####
# store length of series
#####

self$seriesLength <- length(self$x)

#####
#normalize each performance variable
#####

self$x <- (self$x - mean(self$x)) /sd(self$x)
self$y <- (self$y - mean(self$y)) /sd(self$y)
#####
# generate weighted series:      <Feature not used at present >
# self$z <- (self$x*self$weights[1] + (self$y*self$weights[2]

# generate PAA reduction (complete performance, then for individual variables)
#####

self$paax <- PAA(self$x, self$frames)
self$paay <- PAA(self$y, self$frames)

#####
#convert PN to symbolic representation
#####

self$SAXstringx <- convert.to.SAX.symbol(self$paax, self$alpha)
self$SAXstringy <- convert.to.SAX.symbol(self$paay, self$alpha)

#####
#store the SAX representation in an object
#####

self$SAXarrayx[[1 <- self$SAXstringx
self$SAXarrayy[[1 <- self$SAXstringy

```

```

idx<- 2
printed<-0

#####
# loop through the performance tabs in Sheet and repeat calculations pairwise
#####

  for (rec in self$performances) {

    cat(rec)
    cat (" ", " ")

    printed <- printed +1
    self$xls <- read_xlsx(locationPNT, col_types=NULL, sheet=rec,
col_names=TRUE, skip=1)

    self$x = as.numeric( self$xls[[RECcol1 ]
    self$y = as.numeric( self$xls[[RECcol2 ]

#####
# normalize
#####

    self$x <- (self$x - mean(self$x)) /sd(self$x)
    self$y <- (self$y - mean(self$y)) /sd(self$y)

#####
# generate weighted series
#####

    self$z <- (self$x*weights[1] + (self$y*self$weights[2])

#####
# generate PAA reductions
#####

    self$paax <- PAA(self$x, self$frames)
    self$paay <- PAA(self$y, self$frames)

#####
# convert to symbolic representation
#####

    self$SAXstringx <- convert.to.SAX.symbol(self$paax, self$alpha)
    self$SAXstringy <- convert.to.SAX.symbol(self$paay, self$alpha)

#####
# store the SAX representations in vector
#####

```



```

self$SAXarrayx[[idx <- self$SAXstringx
self$SAXarrayy[[idx <- self$SAXstringy

idx <- idx+1

#####
# line break after groups of 15 LINES (or any required number)
#####

    if (printed == 15) {

        cat ("\n")
        printed = 0
    }
}
},

doDistanceMatrix = function(type) {

    if (type==1) {
        rownames(self$dm)<- c("PN", self$performances)
        colnames(self$dm)<- c("PN", self$performances)

        for(i in 1:dim(self$dm)[1]) { # for each row
            for(j in 1:dim(self$dm)[2]) { # for each column
                self$dm[i,j] <- self$dmx[i,j]*weights[1] + self$dmy[i,j]*weights[2]      #weighted
            }
        }
        average
    }

#####
# output DM to disk
#####

    write.xlsx (self$dm, self$locationDM, sheetName="dm-Combined",
col.names=TRUE, row.names=TRUE, append=TRUE)

}

    if (type == 2) {
        rownames(self$dmx)<- c("PN", self$performances)
        colnames(self$dmx)<- c("PN", self$performances)

        for(i in 1:dim(self$dmx)[1]) { # for each row
            for(j in 1:dim(self$dmx)[2]) { # for each column
                self$dmx[i,j] <- self$pairwise(self$SAXarrayx[[i, self$SAXarrayx[[j]
            }
        }

#####
# output DM to disk
#####

```

```

    write.xlsx (self$dmx, self$locationDM, sheetName=PNTcolHead2,
col.names=TRUE, row.names=TRUE, append=TRUE)
  }
  if (type == 3) {
    rownames(self$dmy)<- c("PN", self$performances)
    colnames(self$dmy)<- c("PN", self$performances)

    for(i in 1:dim(self$dmy)[1]) { # for each row
      for(j in 1:dim(self$dmy)[2]) { # for each column
        self$dmy[i,j] <- self$pairwise(self$SAXarray[[i, self$SAXarray[[j)
      }
    }
  }
#####
# output DM to disk
#####

    write.xlsx (self$dmy, self$locationDM, sheetName=PNTcolHead1,
col.names=TRUE, row.names=TRUE, append=FALSE)

  }

},

doSectionDMS = function() {

#####
# now there is a call from Saxify.r to do the section DMs across all performances
#####

  ctr <- 1
  for (sec in self$sections) {

#####
# use the mapped bar numbers.
#####

    sec$getData(self$performances, self$alpha, beatsDroppedStart, beatsDroppedEnd)
    cat("Section - ")
    cat(sec$sectionNumber)
    cat (" : ")
    cat (sec$sectionName)
    cat (" , ")

#####
# only print subSectionName if non-blank (suppress NA)
#####

    if (!is.na(sec$subSectionName)) {cat (sec$subSectionName)}
    cat(" #: ")
    cat(ctr)
    ctr <- ctr+1
  }
}

```

```

cat(" of ")
cat(length(self$sections))
cat (" Variable: ")

#####
#combined series is weighted on other two
#####

    for (type in 3:1) {
      cat (type)
      cat ("...")
      sec$doDistanceMatrix(type)
    }
    cat("\n")
  }
}

)

)

```

## SECTION.R

```
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# (3) commercial use is not permitted of this code or any derived works;
# (4) the code for purposes of this license is deemed to include and cover: Saxify.R file
# and related files Work.R, Section.R and Plotter.R
#####

#####
# Phase 0: Purpose:
#####
# This file defines a R6 class named 'Section' to represent a Section of a
# recording being processed in a run of Saxify. A Work object will be created by
# the calling program to represent all of the performances. For each performance this
# class will then generate one Section object for each structural segment mapped in the
# performed work. This essentially replicated the process performed in Work on the
# complete
# performance - but at a sectional level

#####

#####
# defines the public/private data of the Class and the methods used by it
#####

Section <- R6Class("Section",
  public = list(
    sectionNumber = "numeric",
    sectionName = "character",
    startBar = "numeric",
    endBar = "numeric",
    startBeat = "numeric",
    endBeat = "numeric",
    subSectionName = "character",
    bpm = "numeric",
    timeSignature = "character",
    totalBeats = "numeric",
    startRow = "numeric",
    endRow = "numeric",
```

```

SAXarray = list(),
SAXarrayx = list(),
SAXarrayy = list(),
dm = matrix(),
dmx = matrix(),
dmy = matrix(),
years = c(),
xls = array(),
originalX = c(),
originalY = c(),
x = c(),
y = c(),
z = c(),
seriesLength = "numeric",
paa = c(),
paax = c(),
paay = c(),
alpha = "numeric",
SAXstring = "character",
SAXstringx = "character",
SAXstringy = "character",
varNames = c(),
weights = c(),
frames = "numeric",
performances = c(),
beatsDroppedStart = "numeric",
beatsDroppedEnd = "numeric",
locationDM = "character",

#####
# initialize is the class constructor, called immediately and automatically when an object
# of this class is created. The calling program Saxify.R passes the parameters that are
# shown in parentheses
#####

initialize = function (sectionNumber, sectionName, startBar, endBar,
                        startBeat, endBeat, subSectionName, bpm, timeSignature, totalBeats,
startRow, endRow) {
  self$sectionNumber <- sectionNumber
  self$sectionName <- sectionName
  self$startBar <- startBar
  self$endBar <- endBar
  self$startBeat <- startBeat
  self$endBeat <- endBeat
  self$subSectionName <- subSectionName
  self$bpm <- bpm
  self$timeSignature <- timeSignature
  self$totalBeats <- totalBeats
  self$startRow <- startRow
  self$endRow <- endRow

```

```

    },

#####
# FR10: consider using lapply to replace the 'for loop' in here
#####

getData = function(performances, alpha, beatsDroppedStart, beatsDroppedEnd) {

  self$alpha <- alpha
  self$performances <- performances
  self$beatsDroppedStart <- beatsDroppedStart
  self$beatsDroppedEnd <- beatsDroppedEnd
  self$SAXarray <- list(length(self$performances)+1)
  self$SAXarrayx <- list(length(self$performances)+1)
  self$SAXarrayy <- list(length(self$performances)+1)

#####
# create a DM; add 1 to cover the PNT
#####

  self$dm = matrix(nrow=length(self$performances)+1,
ncol=length(self$performances)+1)

#####
# create individual DMs for each of the individual variables.
# These will output to new tabs on the worksheet
#####

  self$dmx = matrix(nrow=length(self$performances)+1,
ncol=length(self$performances)+1)
  self$dmxy = matrix(nrow=length(self$performances)+1,
ncol=length(self$performances)+1)

  self$xls <- read_xlsx(locationPNT, col_types=NULL, sheet="PT Calcs",
col_names=TRUE, skip=0)

#####
# Only store the bars/beats indicated on the map for this section
#####

  self$originalX = as.numeric( self$xls[[PNTcol1 ]
  self$originalY = as.numeric( self$xls[[PNTcol2 ]

#####

#####
#Adjust for actual start & end (offset is beatsDroppedStart from actual)

```

```

# self$x = self$originalX[self$beatsDroppedStart+self$startBeat:self$endBeat
# self$y = self$originalY[self$beatsDroppedStart+self$startBeat:self$endBeat
#####

  self$x = self$originalX[self$startRow:self$endRow
  self$y = self$originalY[self$startRow:self$endRow

#####

# store length of series – actuals
#####
  self$seriesLength <- self$totalBeats

#####

# for section processing, redefine frames to actual size
# could check here that seriesLength is not greater than self$frames
#####

  self$frames = self$seriesLength

#####

# normalize each performance variable
#####

  self$x <- (self$x - mean(self$x)) /sd(self$x)
  self$y <- (self$y - mean(self$y)) /sd(self$y)

#####

# Generate PAA reductions (complete, then individual variables). For section
# DMs use the actual length of the section rather than the global Frames variable
#####

  self$paax <- PAA(self$x, self$frames)
  self$paay <- PAA(self$y, self$frames)

#####

# convert to symbol string
#####

  self$SAXstringx <- convert.to.SAX.symbol(self$paax, self$alpha)
  self$SAXstringy <- convert.to.SAX.symbol(self$paay, self$alpha)

#####

# store the symbol string representation in an object
#####

```

```

self$SAXarrayx[[1 <- self$SAXstringx
self$SAXarrayy[[1 <- self$SAXstringy

idx<- 2
printed<-0

for (rec in performances) {

  printed <- printed +1

  self$xls <- read_xlsx(locationPNT, col_types=NULL, sheet=rec,
col_names=TRUE, skip=0)

  self$originalX <- as.numeric( self$xls[[RECCol1 )
  self$originalY <- as.numeric( self$xls[[RECCol2 )

#####
# adjust for actual start & end
# (offset is beatsDroppedStart from actual)
#####

self$x = self$originalX[self$startRow:self$endRow
self$y = self$originalY[self$startRow:self$endRow

#####
# normalize
#####

self$x <- (self$x - mean(self$x)) /sd(self$x)
self$y <- (self$y - mean(self$y)) /sd(self$y)

#####
# store length of series – actual
#####

self$seriesLength <- self$totalBeats

#####
# for section processing, redefine frames to actual size
#####

self$frames = self$seriesLength

```



```
#####
# generate PAA reductions
#####

self$paax <- PAA(self$x, self$frames)
self$paay <- PAA(self$y, self$frames)

#####
# convert to symbolic representation
#####
self$SAXstringx <- convert.to.SAX.symbol(self$paax, alpha)
self$SAXstringy <- convert.to.SAX.symbol(self$paay, alpha)

#####
# store the SAX representations in vector
#####

self$SAXarrayx[[idx <- self$SAXstringx
self$SAXarrayy[[idx <- self$SAXstringy

idx <- idx+1
if (printed == 15) {
  cat ("\n")
  printed <- 0
}
}

},

#####
# function to calculate pairwise SAX dissimilarities
#####

pairwise = function (strA, strB) {
  v <- mindist.sax(strA, strB, self$alpha, self$seriesLength)
  return (as.numeric(format(round(v,2), nsmall=2)))
},

doDistanceMatrix = function(type) {
  # FR11: add a distinguishing section identifier to locationDM
  self$locationDM <- paste(locDM, "/dmSection", sep="")
  self$locationDM <- paste(self$locationDM, self$sectionNumber, sep="")
  self$locationDM <- paste(self$locationDM, ".xlsx", sep="")
  self$locationDM <- path.expand(self$locationDM)

  if (type==1) {
```

```

rownames(self$dm)<- c("PN", self$performances)
colnames(self$dm)<- c("PN", self$performances)

for(i in 1:dim(self$dm)[1]) { # for each row
  for(j in 1:dim(self$dm)[2]) { # for each column
    self$dm[i,j] <- self$dmx[i,j]*weights[1 + self$dmy[i,j]*weights[2] #weighted
average
  }
}
# output DM to disk
write.xlsx (self$dm, self$locationDM, sheetName="dm-Combined",
col.names=TRUE, row.names=TRUE, append=TRUE)
}
if (type == 2) {
rownames(self$dmx)<- c("PN", self$performances)
colnames(self$dmx)<- c("PN", self$performances)

for(i in 1:dim(self$dmx)[1]) { # for each row
  for(j in 1:dim(self$dmx)[2]) { # for each column
    self$dmx[i,j] <- self$pairwise(self$SAXarrayx[[i, self$SAXarrayx[[j]
  }
}
# output DM to disk
write.xlsx (self$dmx, self$locationDM, sheetName=PNTcolHead1,
col.names=TRUE, row.names=TRUE, append=TRUE)
}
if (type == 3) {
rownames(self$dmy)<- c("PN", self$performances)
colnames(self$dmy)<- c("PN", self$performances)

for(i in 1:dim(self$dmy)[1]) { # for each row
  for(j in 1:dim(self$dmy)[2]) { # for each column
    self$dmy[i,j] <- self$pairwise(self$SAXarray[[i, self$SAXarray[[j]
  }
}
# output DM to disk
write.xlsx (self$dmy, self$locationDM, sheetName=PNTcolHead2,
col.names=TRUE, row.names=TRUE, append=FALSE)

}

}

)

)

```

## PLOTTER.R

```
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# (3) the code for purposes of this license is deemed to include and cover: Saxify.R file
# and related files Work.R, Section.R and Plotter.R
#####
```

```
# Phase 0: Purpose:
#####
# Plotter.R processes the outputs of Saxify.R. There is presently a manual step to transfer
# data from Excel multi-tab .xlsx files to individual comma-separated variable .csv files.
# FR12: automate the direct linkage but after implementing a database to store all data.
# All code is written in R:
# R Core Team (2013). R: A language and environment for statistical computing.
# R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.
# The program uses two R6 classes (Work.R and Section.R both listed herein) to
# handle calculations. Work.R defines all the performances of a Work. Section.R is
# instantiated from the structural Performance Map which specifies how each
# performance
# is segmented – this may be defined over very high-level structures such as A, B, B' etc,
# or it may be defined over lower level bar groups.
# NOTE: Items tagged FR01, FR02 etc are suggestions for Future Releases of this
# software
#####
```

```
# Phase 1: Load the required R Libraries
#####

#####
# The ‘graphics’ package is part of R. To cite R in any publication use: R Core Team
# (2018).
# R: A language and environment for statistical computing. R Foundation for
# Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
#####
```

```
library("graphics")
```

```

# Cluster analysis library
# (GPL-3 license @ https://cran.r-project.org/web/licenses/GPL-3)
# Maechler, M., Rousseeuw, P., Struyf, A., Hubert, M., Hornik, K.(2018).
# cluster: Cluster Analysis Basics and Extensions. R package version 2.0.7-1.

library("cluster")

#####
# Data analysis
# Alboukadel Kassambara and Fabian Mundt (2017). factoextra: Extract and
# Visualize the Results of Multivariate Data Analyses. R package version 1.0.5.
# https://CRAN.R-project.org/package=factoextra
#####

library("factoextra")

#####
# Excel manipulation library
# (GPL-2 license @ https://cran.r-project.org/web/licenses/GPL-2)
# Adrian A. Dragulescu (2014). xlsx: Read, write, format Excel 2007 and
# Excel 97/2000/XP/2003 files.
# R package version 0.5.7. https://CRAN.R-project.org/package=xlsx
#####

library("xlsx")

#####
# Functions to read/write Excel worksheets
# (MIT+file license @ https://cran.r-project.org/web/licenses/MIT)
# Hadley Wickham and Jennifer Bryan (2018). readxl: Read Excel Files. R package
# version 1.1.0. https://CRAN.R-project.org/package=readxl
#####

library("readxl")

#####

# Phase 2: Initialisation
#####

numberOfClusters <- 4      # Predefine number of clusters based on Elbow
analysis.                  #
                            #
                            # Optimal number of clusters can be based on an
"elbow"                    #
                            #
                            # graph as in following code snippet:
                            #fviz_nbclust(dm, kmeans, method = "wss") +
                            #geom_vline(xintercept = 4, linetype = 2)

folderForInput <- "_OUTPUT1/" # OUTPUT/ is rates, OUTPUT1/ is absolutes etc.

```

```
#####
# folder for outputs
#####

subf <- paste ("clusterPlots k=", numberOfClusters, sep="")
subf <- paste( subf, "/", sep="")

genLoc <-
path.expand("~/Dropbox/PhDDropBox/_EXPERIMENTS/_SCHOENBERG_tipton/")
tattle <- "Phantasy for Violin with Piano Accompaniment Op. 47 (A. Schoenberg) -
Tipton structure"

#####
# Assumes a square matrix: No row titles. Column titles are mandatory
# FR11: Since a DM is technically a triangular matrix, reflected across the diagonal,
# consider how to reduce processing time by directly handling triangularity
#####

if (folderForInput == "_OUTPUT/") {
  xa <- "Bpss"
  xb <- "dbDelta"
} else {
  xa <- "BPM"
  xb <- "dB"
}

#####
# FR12: array of filenames to process (16 is assumed as maximum but this may be
extended)
#####

x <- c("dmFull ALL",
      paste ("dmFULL", xa, sep = " "),
      paste ("dmFULL", xb, sep = " "),

      "dmSection0 ALL",
      paste ("dmSection0", xa, sep = " "),
      paste ("dmSection0", xb, sep = " "),
      "dmSection1 ALL",
      paste ("dmSection1", xa, sep = " "),
      paste ("dmSection1", xb, sep = " "),
      "dmSection2 ALL",
      paste ("dmSection2", xa, sep = " "),
      paste ("dmSection2", xb, sep = " "),
      "dmSection3 ALL",
      paste ("dmSection3", xa, sep = " "),
      paste ("dmSection3", xb, sep = " "),
      "dmSection4 ALL",
      paste ("dmSection4", xa, sep = " "),
      paste ("dmSection4", xb, sep = " "),
      "dmSection5 ALL",
```

```

paste ("dmSection5", xa, sep = " "),
paste ("dmSection5", xb, sep = " "),
"dmSection6 ALL",
paste ("dmSection6", xa, sep = " "),
paste ("dmSection6", xb, sep = " "),
"dmSection7 ALL",
paste ("dmSection7", xa, sep = " "),
paste ("dmSection7", xb, sep = " "),
"dmSection8 ALL",
paste ("dmSection8", xa, sep = " "),
paste ("dmSection8", xb, sep = " "),
"dmSection9 ALL",
paste ("dmSection9", xa, sep = " "),
paste ("dmSection9", xb, sep = " "),
"dmSection10 ALL",
paste ("dmSection10", xa, sep = " "),
paste ("dmSection10", xb, sep = " "),
"dmSection11 ALL",
paste ("dmSection11", xa, sep = " "),
paste ("dmSection11",xb, sep = " "),
"dmSection12 ALL",
paste ("dmSection12", xa, sep = " "),
paste ("dmSection12", xb, sep = " "),
"dmSection13 ALL",
paste ("dmSection13", xa, sep = " "),
paste ("dmSection13", xb, sep = " "),
"dmSection14 ALL",
paste ("dmSection14", xa, sep = " "),
paste ("dmSection14", xb, sep = " "),
"dmSection15 ALL",
paste ("dmSection15", xa, sep = " "),
paste ("dmSection15", xb, sep = " "),
"dmSection16 ALL",
paste ("dmSection16", xa, sep = " "),
paste ("dmSection16", xb, sep = " ")
)

```

# Phase 3: Perform the Run

```

#####
# All code above this point has been concerned with setting parameters and file
locations.
#####

```

```

#####
# process the files for each partial filename y held in string array x
#####

```

```

for (y in x) {

```

```

    fl <- y

```

```

# Each filename is of form: dmFull DB etc, dmSection0 dbDelta etc

fileType <- paste(fl, ".csv", sep = "")

if (folderForInput == "_OUTPUT/") {

  # EDIT APPROPRIATELY

  subtitle <- gsub("ALL", "Bpss, dbDelta", fl)
} else {

  # EDIT APPROPRIATELY

  subtitle <- gsub("ALL", "BPM, dB", fl)
}
titlEx. <- paste (tattle, subtitle, sep = "\n")
title <- paste(titlEx, subf, sep = "\n")

locationDM <- path.expand(paste(genLoc, paste(folderForInput, fileType, sep=""),
sep=""))

oP <- path.expand(paste(genLoc, folderForInput, sep=""))

outPutFile <-paste(oP, subf, sep="")

#####
# suppress error message for non-existent sections - the loop will stop
# after it hits a file not found error
#####

try( theMainFunctionLoop(), silent=TRUE )

}

theMainFunctionLoop <- function() {

  inputs <- read.csv(locationDM, sep=",", header=TRUE, stringsAsFactors = FALSE)

  dm <- as.matrix(inputs)

  #####
  # get the performance recording names. If Error on dimnames(x) <- dn:
  # check csv file is probably missing a column or has one too many (eg PN col),
  # or one extra row
  #####

  recordings <- names(inputs)
  row.names(dm) <- recordings

```

```
#####
# treat as if a Distance Matrix. Input values are already dissimilarities so just need to
# push the values into a triangular format using as.dist
#####

#####
# PAM (partitioning around medoids) can accepts a dissimilarity matrix and
# is less prone to outliers than kMeans clustering
#####

pam.res <- pam(dm, numberOfClusters)

#####
# Ensure that any random numbers will reproduce
#####

set.seed(42)

#####
# Perform PAM clustering on the data frame
#####

xx <- data.frame(pam.res$clustering)

#####
# Visualise the clustering (repel=TRUE parameter tries to place recording names
optimally)
#####

v <- fviz_cluster(pam.res, show.clust.cent = TRUE, main=title, ggtheme =
theme_minimal(), show_clust_cent = TRUE, repel = TRUE)

#####
# name csv files for cluster analytics and write the files
#####

j <- paste(paste(outPutFile, fl, sep=""), "_clusters.csv", sep="")
write.csv(pam.res$clustering, file = j)

#####
# name png files for clustering visualisations then create # .png image from plot & write
to appropriate clusterPlots folder

g <- paste(paste(outPutFile, fl, sep=""), ".png", sep="")

#####
# create graphics device context for png format
#####
```



```

png(filename=g, width = 960, height = 720) #, res = 600, units = 'in')

#####
# for normal PAM clustering view
#####

plot(v)

#####
# output the png(s) and reset the graphics context
# generate silhouette view of this clustering
#####

h <- paste(paste(outPutFile, fl, sep=""), ".silhouette.png", sep="")
w <- fviz_silhouette(pam.res, palette = "jco", ggtheme = theme_minimal())
png(filename=h, width = 960, height = 720)

plot(w)

dev.off()
}

```

## Appendix C. Phantasy – 1952 edition

*In memory of Adolph Koldofsky*

3

### Phantasy for Violin

with piano accompaniment

Arnold Schoenberg  
Opus 47

**Grave** (♩ = 52)

**VIOLIN**

**PIANO**

Measures 1-8 of the score. The violin part begins with a *ff* dynamic and a *passionato* marking. The piano part features a *f* dynamic. The score includes various dynamics (*ff*, *sf*, *p*, *pp*, *f*, *p*, *ppp*), articulations (*passionato*, *dolce*, *rit.*, *a tempo*, *trem.*), and performance instructions (*con sordino*). The piano part includes a section marked *a tempo* and *ppp con sordino*.

Peters Edition 6060

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4

9 *3* *3* *gliss.* *3* *D* *rit.* *a tempo* *D* *G* *pizz.* *G* *arco* *( $\infty$ )* *pizz.* *gliss.* *f*

10 *3* *3* *gliss.* *3* *D* *rit.* *a tempo* *D* *G* *pizz.* *G* *arco* *( $\infty$ )* *pizz.* *gliss.* *f*

11 *3* *3* *gliss.* *3* *D* *rit.* *a tempo* *D* *G* *pizz.* *G* *arco* *( $\infty$ )* *pizz.* *gliss.* *f*

12 *arco* *( $\infty$ )* *f* *pizz.* *D* *gliss.* *G* *f* *12a* *arco* *( $\infty$ )* *f* *pizz.* *D* *gliss.* *G* *f* *arco* *( $\infty$ )* *p*

13 *p* *p legato* *p*

14 *D* *dolce* *G* *( $\infty$ )* *15* *D* *( $\infty$ )* *G*

16 *E* *17* *O* *8va* *f* *V* *A* *f* *V* *A* *rit.* *pp* *Pesante* *ff*

17 *E* *O* *8va* *f* *V* *A* *rit.* *pp* *Pesante* *ff*

18 *mf* *f rit.* *mf* *Pesante* *f*

Peters Edition 6060





38 *rit.* *3* *3* 38b *molto rit.* 40 **Lento** (♩ = 46) *pp* 7

*rit.* *3* *3* *ppp*

41 42 8 8

43 A D 44

45 46 47 *ppp con sordino*

Peters Edition 6060

**Grazioso**

48 49 50 51 52 (♩ = 56) *p*

53 54 55 *poco rit.*

56 *a tempo* *p a tempo* 57 58

59 60 61 *poco rit. .... a tempo*

62 63 64 65 66

**Tempo I** ( $\text{♩} = 52$ )

67 68 69 70 71 72 **Più mosso**

73 74 75 76

77 78 79 80 81

*poco a poco dim. e calando*

*poco mf a poco dim. e calando p*

*quasi legato*



82 83 *allargando*

84 85 *cresc. e accelerando* *molto rit.*

85 **Scherzando** (♩ = 112)

86 87 88 *f spiccato* *p*

89 90 91 92 *f spiccato* *p*

**Poco tranquillo**

93 *p* *dolce* *A* 94 95 96 97 98 99 100 *p* 101 102 *p* 103 104 105 106 107 108 109 110 *p*

Peters Edition 6060

111 *f* 112 *f* 113 *f* *sempre* 114 *f*

115 *f* 116 *f* 117 *f* *poco rit.* 118 *f* *spiccato*

**Scherzando** (♩ = 112)

119 *f* 120 *f* 121 *f* 122 *f*

123 *pp* 124 *pp* 125 *pp* *dim. e calando* 126 *pp*

127 128 129 130

131 132 133 134

135 **Meno mosso** (♩ = 70) 136 137 138

139 140 141

142 143 144 145

146 147 148 149

150 151 152 153

*cresc.* *ff*

*cresc.* *sf*

**Tempo I** (♩ = 52)

154 155 156

The musical score consists of four systems of staves. The first system (measures 142-145) shows a piano introduction with a violin part. The second system (measures 146-149) continues the piano accompaniment. The third system (measures 150-153) features a crescendo leading to a fortissimo (ff) section. The fourth system (measures 154-156) begins with a tempo change to 'Tempo I' (♩ = 52) and includes triplets in both parts.

157 158 159 160

*p*  
*ppp con sord.*  
*pp*

161 162

*f*

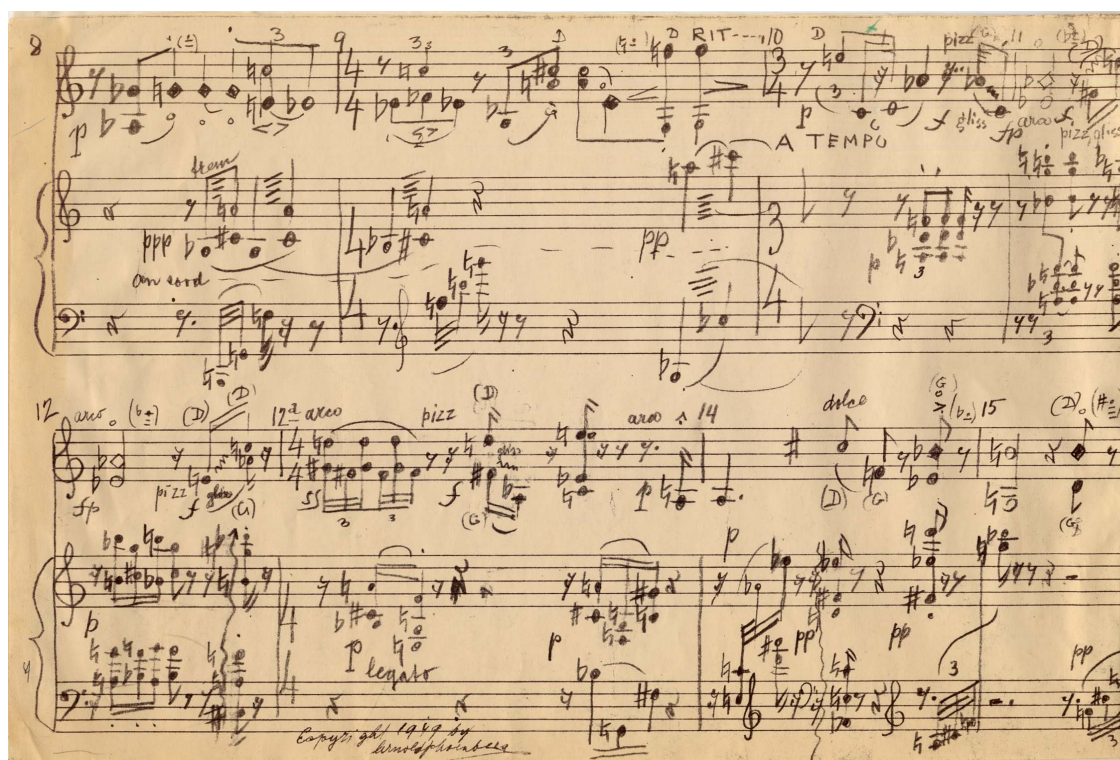
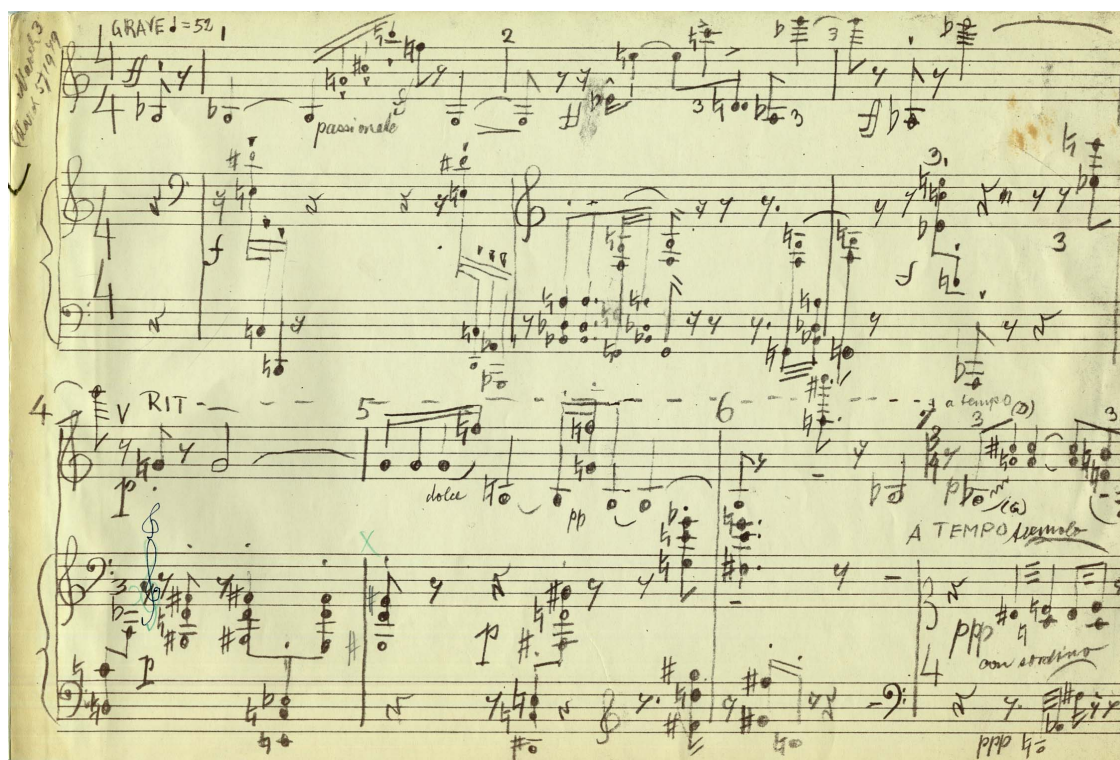
163

*Pesante*  
*ff*  
*mf*

164 165 166 8va

*fp*  
*rit.*  
*ff(A)*  
*molto rit.*  
*sf*

## Appendix D. Phantasy – autograph score<sup>1</sup>



<sup>1</sup> Schoenberg Centre, Vienna.



Handwritten musical score on two pages, featuring complex notation, dynamics, and performance instructions.

**Page 1 (Top):**

- Measures 16-19: Includes markings such as *Rit*, *Pesante*, and *mf*.
- Measure 20: Marked *ATTEMPO*.
- Measures 21-23: Includes markings such as *p*, *mf*, and *RIT*.

**Page 2 (Bottom):**

- Measure 24: Marked *RIT*.
- Measure 25: Marked *Molto rit---* and *p*.
- Measures 26-28: Includes markings such as *pp*, *cresc*, and *p*.
- Measure 29: Marked *pp*.

**Annotations and Markings:**

- Red 'X' marks are present in the left margin next to measures 24 and 26.
- Handwritten notes in the bottom right corner: "⊗ this kind of organ can be applied in similar cases".



Handwritten musical score, measures 29-34. The score is written on three staves. Measure 29 is marked with a forte (f) dynamic. Measure 30 is marked with a crescendo (cresc.) and a fortissimo (f) dynamic. Measure 31 is marked with a piano (p) dynamic. Measure 32 is marked with a piano (p) dynamic and a dolce (dolce) marking. Measure 33 is marked with a piano (p) dynamic. Measure 34 is marked with a piano (p) dynamic and a cantabile marking. The tempo is marked as Poco meno mosso. The key signature is one flat (B-flat).

Handwritten musical score, measures 35-44. The score is written on three staves. Measure 35 is marked with a piano (p) dynamic. Measure 36 is marked with a piano (p) dynamic. Measure 37 is marked with a piano (p) dynamic. Measure 38 is marked with a piano (p) dynamic. Measure 39 is marked with a piano (p) dynamic. Measure 40 is marked with a piano (p) dynamic and a LENTO (1/2 = 46) marking. Measure 41 is marked with a piano (p) dynamic. Measure 42 is marked with a piano (p) dynamic. Measure 43 is marked with a piano (p) dynamic. Measure 44 is marked with a piano (p) dynamic. The tempo is marked as Lento. The key signature is one flat (B-flat).



Handwritten musical score, measures 45 to 54. The score is written on two staves (treble and bass clef). Measure 45 is marked with a circled 'D' and a circled 'G'. Measure 46 has a circled 'D' and a circled 'G'. Measure 47 has a circled 'D' and a circled 'G'. Measure 48 has a circled 'D' and a circled 'G'. Measure 49 has a circled 'D' and a circled 'G'. Measure 50 is marked with a circled 'D' and a circled 'G'. Measure 51 is marked with a circled 'D' and a circled 'G'. Measure 52 is marked with a circled 'D' and a circled 'G'. Measure 53 is marked with a circled 'D' and a circled 'G'. Measure 54 is marked with a circled 'D' and a circled 'G'. The score includes various musical notations such as notes, rests, and dynamic markings like *ppp* and *p*. There are also handwritten annotations in red and blue ink, including 'X' marks and 'G' marks. A small stamp on the right side of the page reads: "ARNOLD SCHENKERS 111 N. 10TH ST. NEW YORK 10011".

Handwritten musical score, measures 55 to 60. The score is written on two staves (treble and bass clef). Measure 55 is marked with a circled 'D' and a circled 'G'. Measure 56 is marked with a circled 'D' and a circled 'G'. Measure 57 is marked with a circled 'D' and a circled 'G'. Measure 58 is marked with a circled 'D' and a circled 'G'. Measure 59 is marked with a circled 'D' and a circled 'G'. Measure 60 is marked with a circled 'D' and a circled 'G'. The score includes various musical notations such as notes, rests, and dynamic markings like *p* and *pp*. There are also handwritten annotations in red and blue ink, including 'X' marks and 'G' marks. A small stamp on the right side of the page reads: "ARNOLD SCHENKERS 111 N. 10TH ST. NEW YORK 10011".



72 *PIU MOSSO*

73 74 75 86

76 *poco a poco dim a calando*

79 80 81

(grandioso...)

*mf*

*dim*

*p*

82 (A) 83 84 85 86

*ALLARGANDO*

*SCHERZANDO*

*ACCELERANDO*

*cresc*

*Molto RIT...*

*spreco*

*8*



Handwritten musical score for "L'Espresso" by Debussy, measures 81-92. The score is written on three systems of staves. The first system (measures 81-92) features a treble and bass staff with a grand staff. The second system (measures 93-98) includes a piano part with a "poco tranquillo" marking. The third system (measures 99-104) features a piano part with a "dolce" marking. The score is handwritten on aged paper with various musical notations including notes, rests, and dynamic markings.

Handwritten musical score for "Die Nachtigall" by Arnold Schöenberg. The score is written on ten staves, with measures 99 through 110 numbered at the top. The notation includes various musical symbols such as notes, rests, and dynamic markings like "p" (piano). The manuscript is on aged, slightly stained paper.



Handwritten musical score for measures 111-120. The score is written on three systems of staves. The first system (measures 111-115) features a treble staff with a melodic line and a grand staff with a complex accompaniment. The second system (measures 116-120) includes the instruction "SCHERZANDO" and "poco rit." above the treble staff, and "p" below the grand staff. The notation is dense with many accidentals and slurs.

Handwritten musical score for measures 121-131. The score continues on three systems. The first system (measures 121-124) includes the instruction "dim e catando" above the treble staff. The second system (measures 125-131) shows a continuation of the complex accompaniment in the grand staff. The notation remains dense with many accidentals and slurs.



132 133 134 135 136 137

MENO MOSSO *p*  
(♩. = 70)

138 139 140 141

142 143 144 145

146 147 148 149

ARNOLD SCHUBERT  
1818-1898  
VERLAG VON F. W. SCHUBERT  
BREMEN



Handwritten musical score, measures 150-157. The score is written on two systems of staves. The first system (measures 150-153) features a treble staff with a melodic line and a grand staff (treble and bass) with a more complex accompaniment. The second system (measures 154-157) continues the piece, with a treble staff and a grand staff. Measure 154 is marked with a tempo change: *154 TEMPO I (♩ = 52)*. The notation includes various musical symbols such as notes, rests, accidentals, and dynamic markings like *cresc.* and *sf*. The paper is aged and shows some staining.

Handwritten musical score, measures 158-162. The score is written on two systems of staves. The first system (measures 158-161) features a treble staff with a melodic line and a grand staff (treble and bass) with a more complex accompaniment. The second system (measures 162) continues the piece, with a treble staff and a grand staff. Measure 158 is marked with a tempo change: *158 TEMPO I (♩ = 52)*. The notation includes various musical symbols such as notes, rests, accidentals, and dynamic markings like *ppp* and *con sord.*. The paper is aged and shows some staining.

Handwritten musical score on aged paper, featuring multiple staves with musical notation, including notes, rests, and dynamic markings. The score is written in a key with one flat (B-flat) and includes the tempo marking "PESANTE".

Key markings and annotations include:

- PESANTE** (Tempo)
- mf** (mezzo-forte)
- RIT-** (Ritardando)
- MOLTO RIT-** (Molto Ritardando)
- March 30, 1947** (Date)
- Arnold Schoenberg** (Composer's name)
- 164** and **165** (Measure numbers)
- X** (Marked on the left margin)
- (A)** (Section marker)
- 3** (Triplet marking)
- mf** (mezzo-forte)
- sp** (sforzando)
- E** and **A** (Chord symbols)
- ok Karpov** (Red handwritten note)



## Appendix E. Corrections in 1978 edition of *Phantasy*<sup>2</sup>

### EDITORIAL NOTES ON THE 1978 CORRECTED REPRINT

The following corrections have been made in this reprint only after consultation with various authorities on Schoenberg's music, all of whom have made a detailed study of this work. No correction has been made without a consensus from these experts. In each case the original autograph, copies of the manuscript, and any other relevant material (engraver's proofs from the first printing, etc.) were carefully examined.

Measure 15-piano, r.h. The original looks as if Schoenberg corrected the  $g\sharp''$  to  $g\flat''$ . The reprint has been accordingly altered, making the dyad a major third.

Measure 16-piano, r.h., 1st beat. Though it is impossible to be certain, the lower pitch of the octave is probably  $b\sharp''$  --thus the parenthesized natural sign before this note.

Measure 17-piano, r.h., 2nd beat. The second dyad is  $e\flat''$  and  $e\sharp'''$ , not  $e\flat''$  and  $d'''$ . Although the upper note appears to be  $d'''$  in the manuscript, evidence points to an error in the omission of one ledger line.

Measure 21-piano, r.h. The dyad is  $e\sharp$  and  $a\flat$ , not  $e\sharp$  and  $a\sharp$ .

Measure 25-piano, r.h. The last dyad is  $b'$  and  $f'$ , not  $g'$  and  $f'$ . The set structure and other contextual evidence make this a certain manuscript error. Schoenberg sometimes made errors by transposing the wrong clef. (In the present instance, the  $g'$  would become B in the bass clef.)

Measure 28-violin. The third note is  $a\sharp''$ , not  $a'$ .

Measure 30-piano, l.h., 2nd and 4th beats. The dyad has been changed from  $a'$  and  $f'$  to  $c'$  and  $f'$ . Again, evidence points to a mistaken clef transposition.

Measure 34. The parenthesized metronome marking of  $\text{♩} = 48$  has been placed in brackets. Although not in Schoenberg's hand in the manuscript, it has the indication that it was approved by Schoenberg.

Measure 38b-piano, r.h. The top pitch now reads  $c''$  instead of  $d''$ .

Measure 62 and 63-violin. The pitch succession is  $f'$  and  $e\flat'$ , not  $f'$  and  $e\sharp'$ . While the natural sign is found in the manuscript, the set form points unmistakably to the flat.

Measure 69-piano, l.h. The dyad is  $B\flat$  and  $D\sharp$ , not  $B\flat$  and  $F\sharp$  (mistaken clef transposition).

Measure 110-piano, l.h. The dyad is  $e\flat$  and  $d\flat$ , not  $e\flat$  and  $d\sharp$ . The manuscript contains an obvious copying error.

Measure 113-piano, r.h. The dyad is  $c\flat$  and  $e\flat$ , not  $c\sharp$  and  $e\flat$ .

Measure 116-piano, r.h. A missing sharp has been added to the  $c'$ .

Measure 162-piano-3rd beat. The first chord now reads  $e\sharp/c'/e\flat'$ , not  $f\sharp/c'/e\flat'$ . The mistake resulted from a proofreading oversight. The last chord in the measure is  $e\sharp/e\flat'/c\sharp''$ , not  $e\sharp/e\flat'/d\sharp''$  as formerly printed.

Measure 163-violin, 4th beat. The dyad is  $c'$  and  $a\flat'$ , not  $d'$  and  $a\flat'$ . The lowness of the note beneath the staff indicates the accidental omission of the ledger line.

Measure 164-piano, r.h. The first dyad is  $c\sharp$  and  $a\flat$ , not  $c\sharp$  and  $b\flat$ . Though the note seems to be b-flat in the manuscript, all contextual evidence points to a-flat.

Measure 165-piano, l.h. The first chord is  $d\sharp/ab/e\sharp'$ , not  $f\sharp/ab/e\sharp'$  (mistaken clef transposition).

Measure 165-piano, l.h., 4th beat. The first dyad is  $d\sharp$  and  $e\flat$ , not  $d\sharp$  and  $e\sharp'$ . Schoenberg's sketches show that the e-natural in his manuscript is a copying error.

The Editors

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